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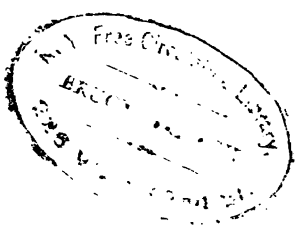
1. Light
2. Sunlight.

Nature's Story-Books

"And Nature, the dear old nurse,
Took the child upon her knee,
Saying: 'Here is a *Story-book*
Thy Father has written for thee.'"

SUNSHINE



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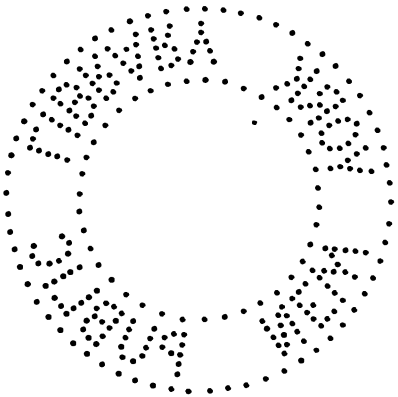

PREFACE

"SUNSHINE" does not profess to be a text-book for any public examination, nor is its chief concern to impart information, although a considerable amount of information is herein stated; nor is its main object to afford amusement, though possibly that element may not be entirely absent.

The sole aim of Nature's Story-Books is to put the reader into communication with Nature herself, to listen to her wondrous stories, and to learn how to address her in her own language of experiment. In such a way have all Nature's children come to know and to love her.

Natural science can no more be learned from reading a book than the violin can. The utmost help that a book may afford, is to relate what Nature has told to others, and if it do not imply, "Go thou and listen likewise," it stops short of its duty. Nature lives! She is accessible to all those who will do themselves the honour of making her acquaintance. The part which the writer, otherwise called "teacher," has to play in these pages is a very insignificant one—that of a mere prompter, whose duty it is to keep in the background as much as possible, and to listen that the children (and as such Nature claims us all) put their questions clearly and distinctly.

It is in view of this fact, that experiment is made the strong point of the book: not merely the simple demonstra-

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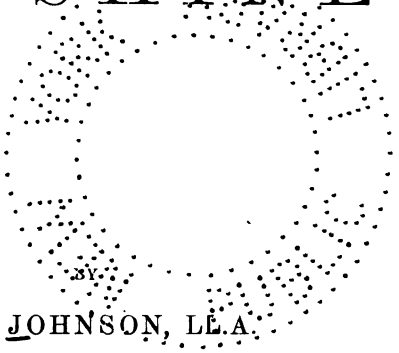

BY

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degree, to children desiring further information on any point which specially interests them.

Children are born logicians. One may throw a little dust in the eyes of a public examiner: but children make straight for the weak point. They seem to know intuitively just where to thrust the question. Indeed it would be interesting to know, on the theory of the Conservation of Energy, what becomes of two salient characteristics of childhood ere a very short stage of life's journey is passed. I refer to the wild imaginings—romances related with all the seriousness of truth, for which children are often wrongfully whipped—the true poetry of childhood; and the ruthless logic which pushes its questions home with a relentlessness which sometimes causes the interrogated one to cry almost in despair, "O, don't bother me any more—run away and play!"

In reference to logic, I may here state a difficulty, which I never fully appreciated until now. I have always deprecated the use of books describing or even giving the results of experiments to be made, and have even abolished such text-books from my classes; just as I should object to a pupil's working a problem with a key open beside him.

In trying to write *Sunshine* upon these lines, I found that it was impossible to deal so with a scientific subject, and at the same time make myself intelligible to the general reader—what to-day is the *end* in view, is to-morrow the *means* of further research. This is the Logic of Experiment.

Although I have had to abandon my principle in the writing of *Sunshine*, there is no need that those who reproduce the stories should do so. An experiment loses more than half its charm by anticipating the result. Perhaps the truth lies half-way. If the children do not see all there is to see, it is sometimes well to *repeat* the experiment, calling

their attention to the special points. "Tell me what I must look out for!" Faraday used to say. In these "Looking Lessons," as they were aptly characterised by the children, I frequently adopted his suggestion. There is no doubt, that the habit of attention has much to do with our seeing. I mention this particularly to prevent disappointment. All the visual phenomena herein described, have been seen times and times again, and may be seen by any one who perseveres in the attempt.

It would have been more agreeable to me to have written anonymously and in the third person; but from the nature of the book, I found this almost impossible. I have tried to be "Guide, philosopher, and friend" to the little folks who will work through *Sunshine*, and this idea is not conveyed to the mind of a child by the impersonal statement of facts. To those named in the stories, a voice will speak from out the printed page; while the confidence of those to whom the stories are new, will be in no way endangered thereby. What I might term the "Laboratory Note-book" style is, after all, the simplest and most natural of writing, and is invariably used by men of science in describing research.

Further, I am reminded that Shakespeare says, "Use every man according to his deserts, and who shall 'scape whipping?" Since methods are here devised and experiments described, for which I alone am responsible, it is well to say that I have no desire to "'scape whipping." No one cares to aim at a ghost. I only ask, that whosoever will do me the kindness of pointing out a weakness, shall also state his remedy in terms as clear and *definite* as possible.

I believe that *Sunshine* will be especially helpful in Recreative Evening Classes, Reading Circles, etc., as well as to ministers and those who in connection with Sunday

Schools are often very puzzled to know what to do next to interest and entertain the young people. To such, I would recommend the Fairy Fountain, Hand-shadows, Fairy Lamps, Fluorescence, Phosphorescence, and so many chapters, that it is difficult to select any for special mention —except Soap-Bubbles.

But it is to the *Lanternist* that I look most particularly as the future exponent of popular science. There seems to be a growing inclination to take "the little hopeful stranger" to our hearts in the evening, when the cares and anxieties of the day are over.

The Lanternist may either, (1) reproduce these lectures as they stand, eliminating or re-converting anything which is clearly unsuitable to his needs. I refer rather to the conversation than to the experiments. He would not be wise in allowing the loan of a few slips of glass, etc., to come between his juvenile audience and an experiment, which they might, with advantage and delight, perform for themselves.

(2) Or, by the help of the Appendix, which supplies (*a*) full details of lantern adaptations, and (*b*) somewhat exhaustive notes (except in cases where the subject will be dealt with later on in the series), expanding the subjects into courses of popular lectures for adult audiences. There is material for many courses of lectures of, say, from three to six in each course. Here I would venture to pass on a hint I received the other day when I replied to a friend, "*Sunshine* is too simple for you to read." "It is *impossible*," said he, "to make a scientific book too simple." I commend this answer to the lecturer, that I may impress upon him, not to express that which is simply put, in language more profound, but rather to translate the added matter into the simplest Saxon. Do not try to get

too much into the time of one lecture. A few points clearly demonstrated and endorsed by many experiments will be much better appreciated and remembered, than a lecture which would enable a student to pass an examination or to write an exhaustive paper.

Before reproducing these lectures, one unfamiliar with the subject should, if possible, first work through the book. In doing so, he will also perceive that some of the Home Experiments are prospective, some retrospective, and since many of these are used to break up new ground, they should certainly be included, as among the best in the book.

In conclusion, I do trust that no one will think after reading this Introduction, that I have any desire to dogmatise on the teaching of science. All ways are good; provided they do not warp the mind or create repulsion. I merely desire to state my profound conviction, that science is not to be *realised* by the exclusive use of formulæ, nor does the study necessarily bear any direct ratio to the expense of the apparatus employed.

To acknowledge my indebtedness to Professor Tyndall seems almost a *truism*. Although I have not consciously followed him anywhere, yet his influence is sufficiently apparent to me as I turn over these pages. Beyond this, I am little indebted to modern English books, preferring rather to trace the various subjects to their first expression in the papers of the several philosophical societies.

Plateau describes his experiments in *Statique expérimentale et théorique des Liquides soumis aux seules Forces Moléculaires*, Paris, 1873. Some of them are also to be found in *Annales de Chimie et de Physique*, tome lxi. Helmholtz's lectures on the theory of vision were delivered in Frankfort and Heidelberg and reprinted in the *Preussische Jahrbücher*, 1868

The Pin-hole Photograph (Fig. 140), which I substituted for my own, was kindly given to me by Mr. A. C. Ranyard, Editor of *Knowledge*; the Slide (Fig. 83) by the Stereoscopic Club. To each I tender my thanks: the same also to Mrs. Fisher, whose kind permission to reproduce the Coal Forest (Fig. 94), from *The Fairyland of Science*, I desire to acknowledge.

My heartiest thanks are gratefully accorded to my publishers, for the numerous and beautiful illustrations which illuminate the text, and to which, I feel sure, the helpfulness of the book will be mainly due. It is almost impossible for those intimately acquainted with any subject, to realise adequately, what are the difficulties which present themselves to those who previously have never considered the matter at all. I trust these will accept my sympathy as evinced in the illustrations, which, almost without exception, are introduced for *practical* purposes. In explaining the figures, I have been mainly guided by the criticisms and questions of the uninitiated ones to whom they were submitted, and who have thereby done me great service. Pictures are to children what the gaily-coloured corolla of the flowering plant is to flying insects. May their curious markings likewise serve to guide the young along the pleasant path of duty, in search of Nature's sweet store-house, where lies the hidden treasure!

My thanks are especially due to three friends for reading portions of the manuscript: Mr. George T. Bruce, M.A., Rector of the Royal Academy, Inverness; Mr. John Willott, B.A., Headmaster of the Public Day School, Macclesfield, and Organising Master of the Technical Classes, Macclesfield School Board; and Mr. Richard Cobden Phillips of Manchester: also to the eminent

Stereoscopist, Mr. W. I. Chadwick, for kindly reading the notes referring to that instrument.

I cannot close without expressing my obligations to the Chief Librarian of Manchester, Mr. Charles W. Sutton, and to his deputy, Mr. W. R. Credland, for the unfailing courtesy and kindness which I have invariably experienced, whilst engaged in verifying statements and revising the manuscript.

Finally, I shall be most happy to receive suggestions in reference to Nature's Story-books. Simple experiments in any department of natural science will be particularly welcome, if not usually found in text-books. My desire is to make this series as *helpful* as possible.

AMY JOHNSON.

MANCHESTER, 4*th April* 1892.

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Lantern Slides (*Copyright*).—The illustrations marked * have been photographed by Mr. Phillips, 41 Oxford Street, Manchester, and any of these may be had as Lantern Slides.

Inquiries respecting apparatus (singly, or in sets), lanterns, etc., should be addressed to Mr. W. I. Chadwick, Optician, St. Mary's Street, Manchester.

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CHAPTER I

WHAT IS SUNSHINE?[1]

To-day we are going to try to learn what sunshine is. I shall turn down the gas until we get a very small bright flame. Now see what we have here—a pill box, the lid of which has been replaced by tissue paper. With a fine needle I make a little hole in the bottom of the box and hold it in front of the flame. What do you see on the tissue paper? A picture of the flame, you say, and you want to know why it is upside down—I will tell you that another day. Look now! I make another hole away from the first. Now there are two images of the gas flame, one through each hole—another hole causes another image. (The teacher worked slowly on for, say, twenty holes.) Now I make another hole—are you keeping count? How many images are there now upon the screen? (twenty-one). I scarcely know how to make any more holes, but I will try. Ah! this time we have gone too near a former hole and the image is not quite so distinct. There are two images really, but you see that this last one partially covers up the former one. Again the same result occurs with this hole that I

[1] Before proceeding to reproduce these stories, the reader is referred to the chapters "Practical Hints," and 'The Mission of the Magic Lantern."

have just made. The holes are now so close together that it is difficult to keep the images distinct. Yet we will make a few more. (After the bottom of the box was well covered with holes it was pulled out altogether.) Now, how many images have we? Can you count them? No,

FIG. 1.—Rays from a candle-flame pass through a pin-hole on to a cardboard screen, and print their own images there.

you have quite lost count. Let us think about this for a moment. One hole gives us one image of the flame. Two holes give?—Five holes give?—Ten holes?—Fifteen holes?—Twenty holes?—A hundred holes?—Five hundred holes?—One thousand holes?—How many pictures can we make with a million holes? Do you think we have a million images here? We have more than that.

Now let us see what we can do with these pennies (or counters). We will lay them down on the desk, on this piece of paper, as many as we can get on to it without allowing them to cover each other. There, now, where shall we put these others?—we shall have to put them on top of the first. We cannot do otherwise. Now I shall make a picture on the blackboard. Taking up the compasses, I draw a number of circles carelessly, some near together, and some too near together, and shade them. If you have a coin or a spool or anything round, you may do the same thing upon your slates. I shall rub this off, so that your drawings will be original. Shade each circle as you make it, and don't mind too much how they cover each other. See what sort of a sketch you can make in five minutes. Crowd as many circles as ever you can into the middle of your slate. Those are all very good. So I shall distribute to those who have made good sketches these smaller boxes of the same kind that I used just now, and will show you further how you may use them in even a more interesting way.

Instead of obtaining an image of the gas-flame, you may, if you wish, produce images of the sun.

As my little box is used up, I shall pull down this black blind and receive the images on this screen, which, you observe, is the glass from a transparent slate. I will put it where you all can see it well. I make a hole in the blind and you see at once a little photograph of the sun on our screen. Another hole gives another picture of him, etc. etc.

Now we have so many images of him that it is hard to tell how many. I will raise the blind a little. How many images are there now on the screen? Charlie says there are so many that they hide one another, and I think that is

very true. There are so many that no one could possibly count them; and these pictures of the sun are not only covering this screen, but now, I will raise the blind a little higher, and you can see for yourselves and tell of other objects in this room that the sun is covering with pictures of himself. "The desks?" Yes. "The floor?" Yes. "My pinafore?" Yes. Now see, I raise the blind a little more and you feel the truth of this. There is Mary sitting blinking. What is the matter, Mary? "Please, teacher, the sun's in my eyes." Oh, is it there too? Now you are all laughing—laughing at the sun for making pictures of himself all over your faces—millions of pictures of himself—even in your very eyes. Is it not strange?

Think of this. Sometimes I see him making very bright images of himself in some window-pane. You have?—That is right. Next time you see it come and fetch me, and we will all go into the playground to look. Yesterday, at sunset, I almost mistook one of these window-photographs for the real sun.

There is just one thing I should like to say, though—that is, that the sun is always doing this, although sometimes the clouds hide him from our sight. On a dull day these sun-images are much fainter here; very few sunbeams struggle through the black clouds, still we know that some do, or we should be left in pitch darkness. Could we see the bright images on the other side of those clouds which are turning their backs to us and their faces to the sun, we should be blinded with their dazzling splendour. This is the meaning of that beautiful Eastern saying—

"Every black cloud has a silver lining."

Notice too that the form of the image does not depend upon the shape of the hole, *if small enough*. Had I not shown

the experiment, first with the gas-flame, you might have doubted that on admitting a sunbeam we received an image

FIG. 2.—SUN-IMAGES. When the sun peeps through the little openings, *of all shapes*, in the thick foliage of trees, we find images of him dotted all over the ground beneath. These images vary in form between the circle and the oval, according to the time of day.

of the sun. You might have said to yourself, "We get a round spot of light, because teacher has made a round hole for the light to come through." Some one make a hole with this

pen. Now, Harold, what shape is the hole you have made? Like a little moon, you say. Yes, 'tis like the crescent moon, yet the image is just the same as with the round hole. Freddy Smith, come and make a hole with this triangular needle—the sun-image is not triangular because the hole is. At home try some other shapes, if you like. When the sun shines through the little spaces, of all shapes, between

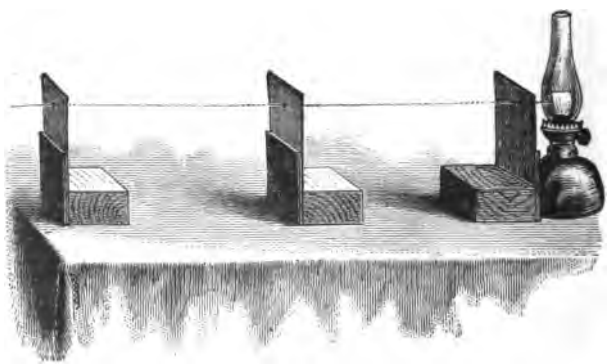


FIG. 3.—Light passes through the holes in the three cards if —?

the leaves of trees, you will find circular images of him all over the ground beneath. Look at this picture (Fig. 2), and don't forget to look out for the reality.

Now take care of these little boxes which I am about to give you. You can repeat our experiment at home for father and mother.

Home Experiments

1. Repeat images of the sun or flame in the pill-box camera or even through a hole in a card (Fig. 1).

2. Make a hole in a card or paper and look through it at the candle or gas-flame. Now make another similar card with a hole in it. Hold one at arm's length, the other near the eye.

Move the cards till you can see the flame through both at once. In how many positions is this possible? Try with three or four cards when you have succeeded with two. Then change your seat and repeat the experiment. You may rear your cards up against something as in the picture (Fig. 3). Turn the *edge* of the flame towards the cards.

CHAPTER II

A SUNBEAM PEEPING IN THE LOOKING-GLASS

I HOPE you have all a very clear idea of what sunshine is by this time. Still there are so many wonderful and beautiful things about sunshine that you do not yet know of, that it will take us some time to find out all.

In our last story we saw that however tiny was the beam that we allowed to come through, we always obtained an *image of the source of light.* When we used the gas-flame, we had an image of the gas-flame on the tissue-paper screen; with a candle we had an image of the candle-flame. Had we used a lamp, we should have obtained an image of the lamp-flame. The sunbeams, you remember, each gave us an image of the sun. The more sunbeams we admitted the more images of the sun we obtained, until they covered each other up, so thickly that we could no longer single them out; just as the pretty snow-flakes (Fig. 7) do in falling, until we see only one white mass of snow.

Now, as the sunbeams make so many images, and as these images cover each other up, we must do our best to get as tiny a sunbeam as possible. If we could admit a single ray of which our sunbeam is made up, we might have a good look at it, in the absence of the others. We cannot, however, single out just one ray, I am afraid. We

will use this fine needle. Now we have a very fine line of light, as you see. You have used in your lessons my favourite test for a straight line. Now all your hands go up! What is it then? "A piece of fine cotton." That is only half an answer though. Here is a piece of fine cotton.

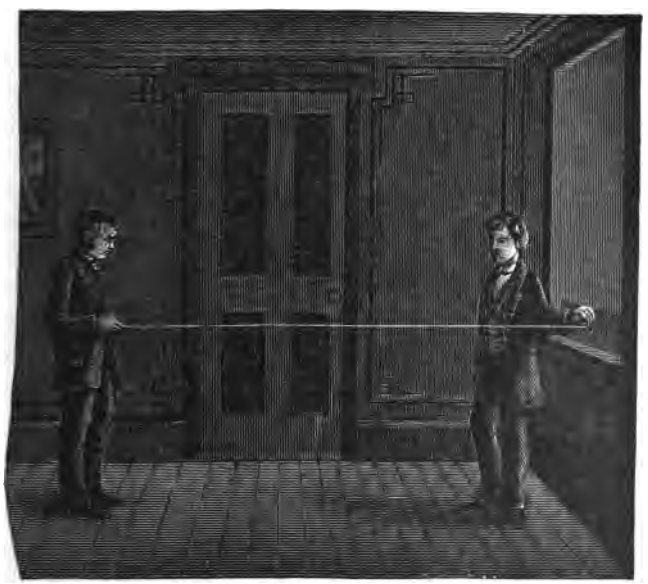


FIG. 4.—"George and Harry, take this piece of white linen thread and stretch it tightly throughout the length of the sunbeam."

I hold it so, in both my hands. It forms a beautiful curve. How shall I make it a straight line? "You must pull the cotton tight." Ah, Mary, you forgot to say so before, did you not?

George, go and take hold of that line of light and fetch it here! You laugh. Go and feel at it and tell me what it is made of. You say it is made of dust, and that it warms

your hand like a fire, but that you cannot bring it. It is not made of dust, as we shall find out by and by, though dust has to do with our seeing it. George and Harry, take this piece of white linen thread and stretch it tightly throughout the length of the sunbeam (Fig. 4). It is really a bundle of straight lines of light called rays. Although the hole through which the beam comes is so tiny, we cannot make one small enough to admit just one ray. Now, Tom, you go and feel at it. He says it feels hot. Remember, then, that heat is always present where light is.

All heat and all light come originally from the sun, whether it be the light and heat of a lamp or gas or fire; it is merely sunlight that has been *saved up*. Moonlight, too, is sunlight second-hand. George, you thought the beam was made of dust. See, with this red-hot poker I will burn up the dust. What do you see now? Black smoke, you say. Ah, it looks almost like it. It has put the light out from our sight. How is that? I will show you. Here is a mirror, or, as you would say, a looking-glass. I place it for the sunbeam to look in. See, the light strikes it as a ball would, and then bounds off again to the wall, making another straight line and a spot on the wall (Fig. 5). Whichever way I turn the glass the beam moves too. Its path is always a straight line. See, I can send the straight line anywhere—to you, Freddy—to you, Minnie—now up to the ceiling.

You see these little square screens. I shall show you how everything that I use is made, so that you will understand how to do the same things yourselves. I have taken this chalk-box to pieces, leaving only the bottom and one long side attached. To this I have tacked a card from the wall. One side of the card is papered white, and over this other side I have spread black tissue-paper. I

might have inked over the cards instead; perhaps you would find that an easier plan. You see they make firm and handy little screens for moving about on the desks. I have made a hole in the centre of each card. The hole is about the size of the uncut end of your black-lead pencil.

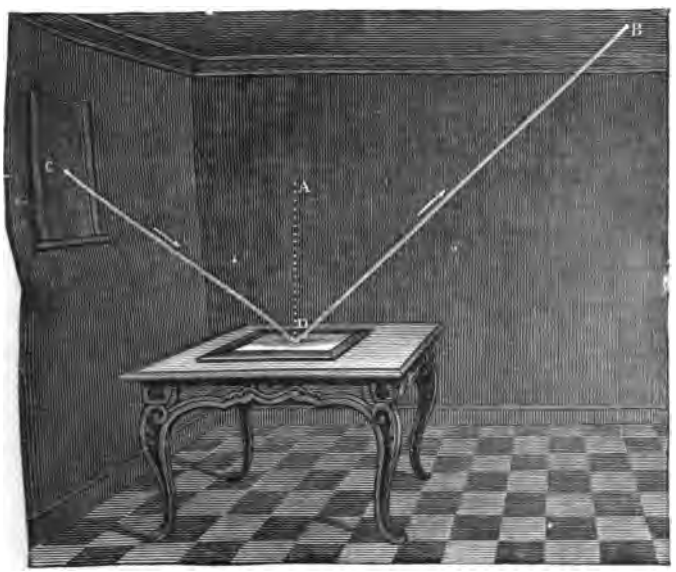


FIG. 5.—A sunbeam peeping in the looking-glass.

Now, Paul, you take this mirror in your hand, and see if you can send the sunbeam through the centre of both of these *targets*, as we might call them, on to the white screen beyond.

I wish that you boys would practise this experiment at home till you can do it quite easily and steadily both with gaslight and sunlight. It is easy enough to do with gas or candle, but not so easy with the sun. Why?

I shall very often want a boy who can do this, for we require a steady beam of light in our experiments. You will recognise your home experiment of looking through the cards; for unless the holes are in exactly the same straight line with each other, the light cannot pass through. You may try with any number of targets. If you like you may put a thread through the holes. We have one little boy who manages this very nicely. I daresay you know

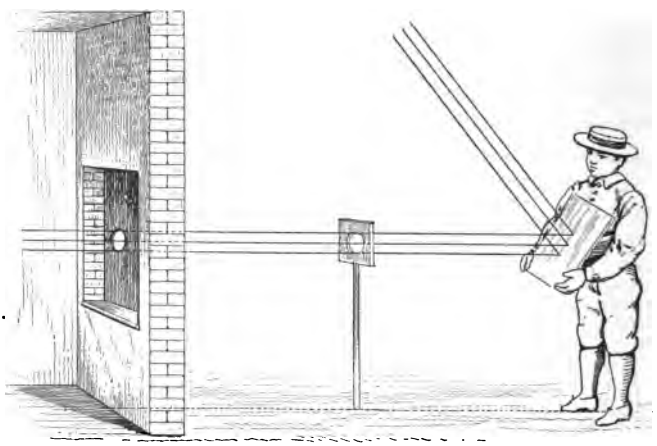


FIG. 6.—THE "SIMPLEX" HELIOSTAT.

his name. He is always on the alert. He understands my look, and is in the playground with his mirror in an instant, sending us a horizontal beam of light into the room, such as you saw just now (Fig. 6).

Through these targets, or sight-vanes as they are usually called, soldiers are able to telegraph to each other in times of war. A flash of light reflected even from a silvered mirror as big as a threepenny-bit, could be seen for ten miles. We will use the penny mirror, fixed so as to throw a flash of light

on this screen. Long flashes and short flashes are made, *not by moving the mirror*, but by sliding a piece of paper over it for a longer or shorter time. Telegrams at the rate of twelve words a minute may be sent forty miles in fine weather by this means. I will show you how. Suppose we want to telegraph your name, "Tom." I make a long flash for "t," thus; three long flashes for "o"; then two long flashes for "m." "Please do some more!" Two short flashes stand for "i"; three short ones for "s"; four short ones for "h"; one short one for "e"; short, long, short stands for "r"; one short one for "e"—"Tom is here."

Has any one of you a gun? Don't be alarmed! You have one at home, Isaac, you tell me. Do you know how to shoot? Come, take my pointer, and show me how you would fire at that nail on the wall. Watch him, boys! See, he is looking along the pointer at the nail! Why do you do so, Isaac? "I want to aim straight." You want to send what you shoot along the same path as those rays take in coming from the nail to your eye? That is the most direct way to the nail. A sunbeam always comes by the shortest route, viz. a straight line.

Here is a piece of wood, one side is planed, the other side is rough. I daresay you have seen the carpenter hold the wood up to his eye, so, to see if he has planed aright. If so, the light will come along the level surface. If it is not quite plane and level, each little hill or mound of wood will screen off the light, making shadows as this other side does. Therefore he does not see the light because of these little shutters.

When I plunge my eye into this beam I perceive that it is exceedingly brilliant, because my eye meets the light as it comes in through the blind. You also see the beam, but much more faintly. But now, Mabel, I send the beam to

you, by turning the mirror. Now the sunbeam enters your eye, and you mark how luminous it is; but your companions see only the faint track of the beam proceeding to your eye.

Now I take this piece of plain glass in my hand instead of the looking-glass; it seems to answer nearly as well; or

FIG. 7.—SNOWFLAKES (magnified). These are *faithful* images—what have they in common?

this piece of china. Nancy, you have some bright buttons on your frock; come and stand here in the sunshine. Is that a new penny I saw in your hand, Tom? "Yes." Go and try it. Now take this cup of water, Ben, and try it. Yes, that will do also. Now I shall try something still more curious. I fill this saucer with ink. See what a capital mirror it makes. Are you surprised? Not if you have seen the lamplight or moonlight reflected in the mud-puddles in the street. All these curious objects, then, are

mirrors, for they are able to alter the direction of the light. I take a handful of flour and gently sprinkle it in the sunbeam. Oh, how bright! The tiny bits of flour roll round and over as they fall, and turn the light in every direction, making that bright glow which lights up the room. Even those little specks of dust that you saw floating in the sunbeam acted as mirrors, which in fact they were. You missed the light in a moment when I burned up the motes. Each is a little mirror sending the light that strikes it straight to our eyes, else we could not see the sunshine. That dark space which you thought was filled with black smoke, was simply a part of the sunbeam which you did not see at all, *because your eye was not opposite to it*, nor were there any dust-mirrors to turn the light in your direction. But you saw the spot on the wall beyond all the time, you say? Yes, that was because the bits of plaster turned the light for you.

Now, Minnie, to prove this, come and hold this button in the path of the sunbeam, where I burn up the motes with the red-hot poker. Now look into that dark space. Do you see the light? "Yes."

I want you never to forget that, so I shall write on the board (not to be rubbed off)—

1. *We do not see the light unless it comes in our direction.*
2. *Light* (ordinarily) *proceeds in straight lines.*
3. *Heat is present where light is.*
4. *When the sun shines on any object whatever* (*e.g.* a red-brick wall, a house, or a tree), *he is stamping it over with images of himself, so thick and close that they hide one another as the snow-flakes do.*

Home Experiments

3. Practise signalling with the heliograph or sun telegraph. Use the Morse Alphabet.

4. Pin a piece of black velvet to the cuff of your sleeve, so as to fall over your wrist when you extend your hand (palm upwards). On the other cuff pin a piece of white paper in a similar position. Place a bit of tin or a bright button in the palm of one hand, and a piece of glass in the other. Hold each of these things in succession in the path of a sunbeam or light from a candle. Take notice which of these produce images and which do not.

CHAPTER III

A SHADOW PANTOMIME

In our lesson on the sunbeam we learned that the light of the moon was but reflected sunlight, such as we often see glowing in some window opposite the setting sun. If you are inclined to doubt this you have only to compare the moon's brightness with that of a white cloud near her—the one will be about as bright as the other. Perhaps you may have noticed the wet slates on the roofs opposite lit up like sheets of pure silver with the glorious light of the sun. If you have never observed this, it has been there just the same. Look out for it, and when you do find it, call my attention to it that we may see it together.

The other day as I sat in the park I observed something very curious. I saw a figure moving towards me, though it was still near the other end of the park. On this figure the sun appeared also to be approaching. I gazed at the sight for some minutes, wondering what could be the cause of the strange appearance. I said surely it is a soldier with a star on his breast. The dazzling light increased as the figure drew nearer, and I saw that what I had mistaken for a soldier must be a woman yet a long way off. I was more puzzled still at the singular effect, so much that I determined to walk towards her—past her, in

fact—to satisfy myself as to the cause. More and more glorious became the little sun as I neared the figure. I walked slowly past, observing that the poor woman was

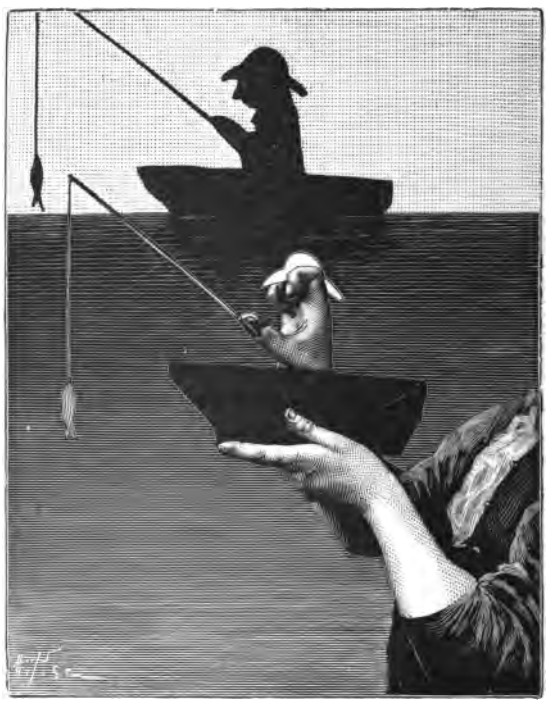


FIG. 8.

carrying what seemed to be an almost new satchel of *black American cloth.* The setting sun in all his splendour was depicted there — hence the illusion. Of course I knew all about it before, and had told little folks many times how the sun shines on the moon's dark face,

lighting it up with his own sweet smile—sees there an image of himself as in a mirror. But here was an experiment ready made for me — walking past me — which impressed my eyes as some strange voice affects the ear, never to be forgotten. What was there behind the satchel, though? Why, exactly behind there was darkness, for the satchel shut out the sunshine; and now I shall lower the black blind and try to show you the effect by admitting a sunbeam on to Nellie's ball, which I have suspended by this cord. Do you see how the sun lights up our little moon. Those who are at the back of the room perhaps do not see the moon at all. Why? Because the moon stops the rays of light, makes a shutter, as it were, at that place. We can show this by drawing closer the screen behind. The space immediately behind the ball is called the shadow. Outside the real shadow is an imperfect shadow.

On closing the hole in the shutter with this gummed paper and lighting the gas instead, I shall be able to show you with this bat's-wing flame, first, that on turning the *edge* of the flame towards the object we get a *sharp* shadow, and when the *broad flat side* of the flame is turned to the object we obtain *also the faint shadow.* Willie! go near to the screen and stand there. Notice how dark and distinct Willie's shadow is. Now step back two or three paces. Do you notice, children, how the outer shadow grows larger and becomes more hazy. I have here pictures of a house, a boat, a rabbit, etc. These pictures have been pricked by you when in the Infants' school. See, I hold this card (which has been dipped in ink and dried) close to the screen. The effect is not pretty. Now as I hold it at a little distance the shadows blend and soften, and the picture begins to look more real.

But I must not go too far away, as you see, or the image becomes confused and indistinct.

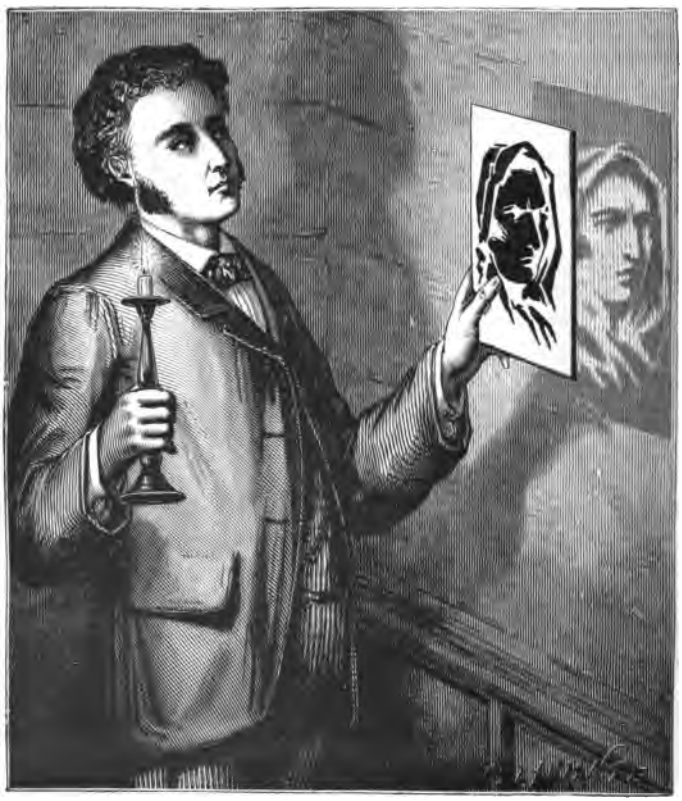


FIG. 9.

On this plate of smoked glass I make a picture of a head and hold it before the screen. There are many pretty experiments which you can try at home when the gas is lit and blinds drawn down. I will show you a few,

and doubtless you will find out many more for yourselves without any hint from me.

I daresay, Harry, when friends from a distance come to see you, they remark what a big boy you are getting. I think all you boys and girls are growing; if not there must be something wrong. Those of you who have been told at different times that you are growing very fast, stand! Yes, nearly all of you, that is right! Yet those who live in the same house don't notice the growing the same; you grow slowly and unobserved. Ernest, should you like to be a man? "Yes." We will watch Ernest grow into a man. Go and stand by the screen, Ernest. Now walk very slowly towards me. Do you see how fast he is growing? There! Now watch the screen and I will walk towards it. You see I am growing smaller and smaller.

This time I shall place a candle upon the floor. Now, James and Harold, come forward. James, go near the screen and bend forward. Harold, come near the light, you are to have a donkey ride; in a certain position you will appear to ride on James's back. There! see if you can keep pace together! Tom, can you jump as high as the ceiling? No? Well, you shall try. Stand there, back to the screen, and jump over this candle which I have placed on the floor. You see you don't know what you can do until you try! Freddy, come and jump down from the ceiling. How? Face the screen and jump over the light.

Harriet, I wonder if your mother thinks there is not another little girl in the world like you. Mothers do say such things sometimes! Come here and stand. Tom, hold this candle. Do you see Harriet's shadow? Would you like to see another Harriet? Ben, I shall light this candle and give it to you. Please stand

just there. Now, what would your mother say, for we have got two Harriets on the screen? Sam, come and take this candle and stand here by me. Now, boys, the three Harriets will conclude with a dance. John, go and stand

FIG. 10.

by Harriet and take her hands. Both of you stand still. Tom, Ben, and Sam move the candles and keep time to the verse which the class will sing for you.

As our time is up you may continue your experiments at home—as often as you like! I will also show you from

time to time how to make hand-shadows (Figs. 8, 10, 35, 39, 72).

Home Experiments

5. Shadow practice.

6. Make a small hole in the shutter ; I daresay you have made one already. Open your drawing book at a clean page and hang it over the back of a chair opposite to the hole (when the sun is shining brightly, but not peeping in). Draw me a picture of what you see. The hole may be the size of the uncut end of your black-lead pencil.

CHAPTER IV

THE COLOURED PHOTOGRAPH

YOU were all delighted with your last experiment. You have talked of nothing else. You tell me that you expected to see something wonderful, but had no idea that you would obtain such a beautiful picture. Sam has coloured his drawing with crayons to make it more true to what he saw. I am surprised to find that one little girl did not perform the experiment. She *guessed* what the effect would be, and this is the result. You see that she has drawn in yellow crayon a picture of the sun. No! don't laugh at poor Edith, she thought she *knew* and could proudly say she did not *require* to try the experiment. I hope this will be a lesson to you boys and girls never to guess when you have the opportunity of making yourself *certain*. Don't neglect one experiment—if you do, you miss a great treat. We will just show Edith what she has lost. I will fasten with drawing pins this large sheet of paper which I brought from the printers, on to this blackboard, and place it on an easel at a little distance from the window, and lower the black blind. I make a small hole. Now, Edith, what do you see,—an image of the sun? A coloured photograph (Fig. 11). Why do I call it a photograph, you ask? Because that is what it really is.

Much better in fact than an ordinary photograph, because you have the *natural colours*. Unfortunately our photograph is not *fixed*; that is to say, if I move away the screen to the right or left, very far, the picture will vanish, as you will

FIG. 11.— A COLOURED PHOTOGRAPH.

see presently. First, we will make a clear round hole in the blind about the size of a halfpenny, then I shall fix my little pocket lens in front of the hole in the blind, by means of this gummed black paper. Now you see the image is much *clearer* and sharper than before, but it is not so *true*. The photographer always forms his picture in this way on a screen first, or rather *the rays make the*

picture for him, and if you sat inside his camera or black-box (Fig. 12), you would be able to see the photograph he was going to take. Fortunately our camera is a very large one and you won't be at all in the way. I can't promise to take the photograph of any one of you—stop, there is an old woman with a red shawl on coming down the road. I know what you are laughing at, she seems to be walking on her head, and you are surprised that the groceries don't fall out of her basket. I wish she would drop one of those little parcels, you would then have the pleasure of seeing it fly *upwards*. Frank! you may go out into the road and we will look at your photograph; take this pen with you and hold it up. Do you see him?—he is upside down too—and the pen?

It will be some time before the photographers can make coloured pictures like these to remain, though we have succeeded a little in that way.

Now we will draw up the blind, and by means of a sketch on the board I will try to explain to you why the image is inverted or upside down. Frank, where is my pen? You children have seen the inverted image of this pen on the screen. Now look at the board while I draw its picture. Now here is the hole in the blind, through which each ray from the pen must pass into the room. Remember that the rays of light are straight lines. I will use this ruler to rule the lines. First, I will rule a straight line from the middle of the pen through the hole. Now we will represent a ray from the top of the penholder through the hole—the end of this line will be the point of the pen-nib (image). So you see the top of the pen-holder will be at the bottom of the picture. Now we will draw a ray from the point of the pen-nib, also through the hole. You see where the point comes out at the top of

the picture. We could trace other rays in their passage in the same way.

There are some boys and girls, and indeed some grown-up people, too, sometimes, I find, who can never understand a diagram or plan. That is why I am teaching you so early to begin, but I shall not entirely depend on the drawing. You recognise this little target with the hole in it. It is what we used for sending the sunbeam through, is it not? Freddy, come and hold the pen steadily. Every little point or speck of this pen sends a ray or straight line of light through the opening. The ray carries with it the colour of that point from which it comes and prints that colour on the screen. All the rays do this and the result is a picture. There are many million rays of light coming from the sun to this penholder, darting off thence to our eyes. We cannot represent all of these. We may, if you like, send as many through the hole as it will admit. We will use these coloured sticks or straws, whichever you like. "The sticks!" Very well, we have long sticks of all colours here. I borrowed them from the Kindergarten: no doubt they recall many pleasant associations. What is this? Some wax? Thank you, Herbert,

FIG. 12.—PHOTOGRAPHIC CAMERA.

you seem to guess what I want. I shall be able now to fix the sticks to the penholder. First, I must set up this penholder some way, so as to be quite vertical. Get me an empty bobbin, Alice, please, and I will push the end of the penholder into it. That will do. We will consider the part just above the bobbin to be the end, for all practical purposes. Now, this blue stick is attached to the centre of the pen: it goes horizontally through the hole, and marks the middle point of the penholder on the hand-screen which I draw up close to receive it. This red stick we will fix to the point of the pen-nib after passing it first through the hole. It slants right down to the bottom of the screen, where we must represent the nib. To the bottom of the penholder we will affix in the same way a yellow stick. This ray proceeds from the bottom of the penholder through the hole to the *top* of the screen. Now that we have fixed the principal points, we may put in some rays between, before drawing our picture on the screen. Let us now trim the ends of the sticks so that each will touch the screen, as some are longer than others. Now we have made a complete picture. But it is upside down. Yes, and what is stranger is that at the back of your eye a little white screen is stretched (not of paper certainly), and on it is an inverted, or upside-down image of this penholder as I hold it up before you. How do we know this, you ask. Well! our lesson has shown us why this must always be so when rays of light go through a small hole, and the pupil of your eye is just such a small opening. By and by I shall give you a lesson on the Eye. Then I hope to show you that inverted images may be seen at the back of the eye of a recently-killed animal, on removing the tough leathery coat which wraps round this delicate screen called the *retina*. Until that time I want

you to bear in mind our lesson of to-day. You would hardly believe me, I suppose, if I were to tell you I had never seen one of you in my life. You children before me—*I never saw you*—never shall see you. All that I have ever seen of any of you, is an inverted image of you at the back of each of my eyes, on a wonderful screen which sends a message to my brain to tell me what you are like.

There is just one point more that I wish to show you with this experiment. That is, the *size* of the image. As

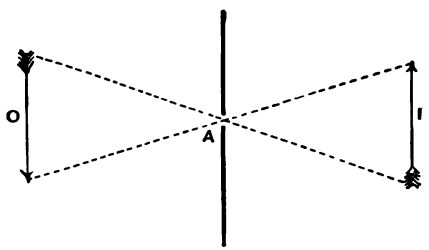


FIG. 13.

I move the target nearer to the screen the size of the image grows *less*; as I move it nearer to the object the image grows larger. Some of you found this out for yourselves at home and told me of it. Of course you can't move your shutter at home in this way, but you can do what answers the same purpose. What is that? "Draw up the screen closer." Right, Charlie, and that is what you did.

At home you may repeat our experiment. A long straight object, with ends unlike, is the simplest to manage at first, *e.g.* a needle or a pencil. For this reason an arrow is often used to illustrate it (Fig. 13).

Home Experiments

7. To-night, at home, I wish you to make quite a new kind of mirror. Drop a pebble, coin, and any other little things you think of that will sink to the bottom of a glass of water.

Now take the glass in your hand, and raising it above the eyes look up through the water to the surface, so. You will see there, as it were, a mirror laid face downwards upon the water, and in it you will see the images of the objects in the tumbler.

Or you may place the glass near the edge of the table and objects near it on the table, then bend down and look up into the tumbler.

If you have a globe of fish at home look upwards to the surface, where you will find a true picture of all below, and perhaps you may understand how a person bathing, laid on his back under water, sees images of fishes and other objects which are in the sea as though they were swimming about in the air above him.

8. Make a list of all those objects at home which you can see your face in, and also another list of all the objects which shine when a light is brought near them.

CHAPTER V

TRAPS TO CATCH SUNBEAMS—FAIRY LAMPS

SINCE we met last a little girl has asked me a very interesting question, which I shall try to explain for all of you. You remember I gave you an experiment to perform at home. You have all done this? Yes, I was sure you would. Louisa wants to know why we do not get an image in each case. She says we ought to do. Let us see. First, we will take our mirror and place it in front of a lighted candle. Here we obtain a distinct image of both candlestick and candle in the mirror. Now let this piece of white paper take the place of the mirror. We have no image formed, but instead there appears a spot of light, with a bright cloud or halo all over the paper. Let us now try this newly-ironed handkerchief. Now, even the spot has gone, and the bright cloud of light has spread itself equally over the surface. Place your own hand in the beam. It is lighted up, but still there is no image. See how the light dances on my cuff!

Now let us try to picture on the blackboard what takes place. Did you ever ride in a cart over a rough country road? "Yes." How did you like it? It nearly jolted you out of the cart, you say, and you were glad to get on to the paved roads of the town again. Did you ever ride in a tram-car? How did that go? "It seemed to slide

along." Yes, the wheels run along smooth bars of steel, and the movement is scarcely felt by the passengers. These rays of light go through the same experience. When they strike on a rough surface they are jolted and jerked out of

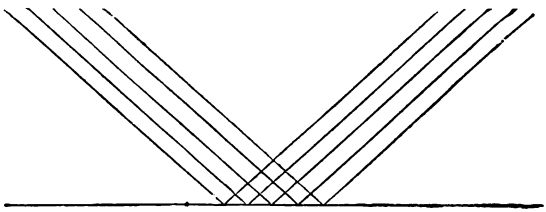


FIG. 14 (1).

their proper path, and, as you know, you cannot make a correct picture, however straight your lines may be (rule them if you like), unless they are in right positions with respect to each other. For example, you could make me a house, I daresay, if I gave you some of these little sticks,

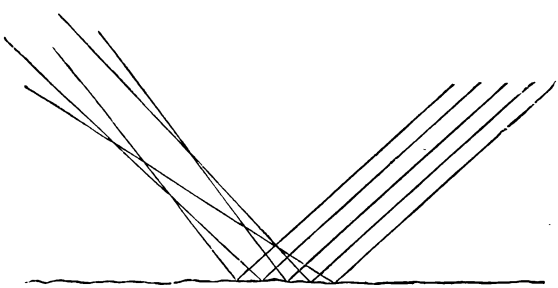


FIG. 14 (2).

provided you arranged the sticks in their right places. Now, in the case of a perfectly smooth surface, such as glass, polished metals, or still water, we have an image formed. With the paper, handkerchief, hand, etc., we had no image. You don't think the paper is rough—it feels quite smooth. Let me show you. Look at it through this magnifying glass.

You are astonished—can't believe it—it is like a newly-laid road. Your hand is still rougher. Every one of those little bits, that seem to stand up on the paper, is itself a mirror, reflecting the light; and as these mirrors are slanting in every direction, so the rays are being reflected here and there and everywhere. You can make no picture in that way.

Tell me, Lucy, before I make this diagram on the board, whether you like best to play ball on asphalte, on the flags, on the cart-road, or on the heap of sand and stones where

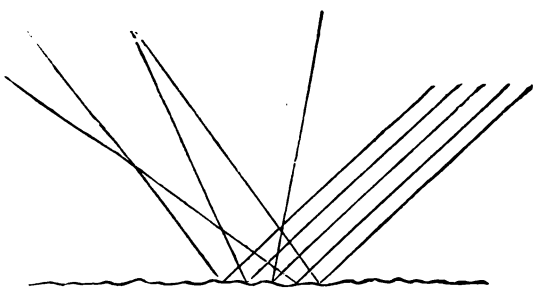


Fig. 14 (3).

the men are digging near the school? In the first drawing (Fig. 14, 1) we have represented a smooth surface, such as glass or polished metal, where the light is *regularly* reflected; this corresponds to bouncing your ball on the asphalte or flags. The second drawing (Fig. 14, 2) shows how light is reflected from paper. Look at the *ground line*; it is rougher than the first—we might compare this with the cart-road. On the sand-heap, you never know where the ball will dart off next, if it bounce at all. So it is with the light rays reflected from the handkerchief. This is shown in the third drawing (Fig. 14, 3). On the black velvet they will scarcely reflect at all.

But I am afraid, from what I have said about sticks and balls, that you may get a notion that light is a *thing*. Remember, then, that it was not the ball, but the *bouncing*, that I drew your attention to, and the *position* of the sticks. Bouncing a ball, jumping in the skipping rope, swinging, dancing, walking, running, swimming, leaping, are all familiar to you, and quite real, yet they are not things. Neither is light a thing, though a candle is; so is a lamp, and so is the sun. Just as a piano is a thing, and so is the child who plays it, but not the playing. A written copy is a thing, and so is the child who writes it, but the movement of the arm, *i.e.* the act of writing, is not. Which of these movements light most resembles I must tell you another day; enough for to-day to know that *it is Movement.*

Now, after this dry explanation we will have an experiment—a very beautiful one. I put a piece of black stuff on the table, then place upon it this clean glass jar. I daresay you may have seen some like it in confectioners' windows. Now we will lower our black blind and admit a sunbeam. I cut a slit an inch long in this card. Freddy, come and hold this mirror at an angle of 45 degrees over the jar. Do you know how? You see the horizontal[1] beam of light which Ernest is sending through the target? Move the mirror till you cause the sunbeam to turn a right angle. The reflected rays must pour perpendicularly down that hole. You know how to do it now. Remove the mirror. I will light this piece of brown paper and put it in the jar. I hold my hand over the neck of the jar for a

[1] We shall often speak about horizontal and vertical directions. Horizontal lines lie flat down as on a table, floor, or ceiling. Vertical lines stand straight up, as the walls of a room do, or as you yourself stand.

moment. The paper has burnt itself out. Now I put the card on again, and do you direct the beam vertically into the jar. Down the centre of the jar is a radiant ribbon of light, the rest of the jar is pitch-black. Now the whole inside is intensely illuminated (Fig. 15). I put the card on again. Much of the smoke has got out of the jar by this time. The bright ribbon that was, is very dim, and inky streaks and patches run through it. How is this? The beam of light is disappearing because the little mirrors are fast escaping. How strange!

FIG. 15.—A FAIRY LAMP.

Now I exchange the jar for a clear glass tumbler filled with water. The beam lights it up just sufficiently to be seen in the dark. I add a teaspoonful of milk to the water and stir it well. Throw the beam down once more, Freddy. The tumbler of milk and water shines like a lamp, and lights up the room so that we could see to read by its strange white haze. Throw the beam somewhere else, Freddy. Now the room is dark again. Send it back again. The whole room is lighted by those tiny particles of milk floating in the water, catching and reflecting the light in every direction, so that the whole tumbler seems filled with them. Some of the mirrors turn the light in one direction, some in another. It is in this way that we are able to see the people and things about us. The light

of the sun or a lamp falls upon the tiny specks in the air and is reflected into our eyes, and we see the objects round about us. Very few things reflect light so brightly as to form images of the source of light, though sometimes this is the case, as when the sun shines into a window and imposes there so bright an image that our eyes are almost blinded, and we really think it is the sun himself. But a milder scattered light is more common—a light which enables us to look around us and distinguish objects without pain. Out of doors the clouds, fields, water, houses—and inside, the walls, furniture, and even our own bodies reflect the light again and again, in every direction; like the paths of balls that are kept moving in a zig-zag course as you play rounders—all the spaces indoors and out are filled with faint sunshine (Fig. 16). At night, when we no longer see the sun, the light of his countenance is reflected for some time in the clouds above him, and the sunset clouds reflect it again and again to us, until it grows too faint to be noticed. Sometimes when the sun seems to be thickly wrapped in dark clouds, we see streaks of light breaking through the darkness. These are beams of sunlight reflected by the dust and fine mist of the clouds, each speck of which reflects his light (Fig. 66).

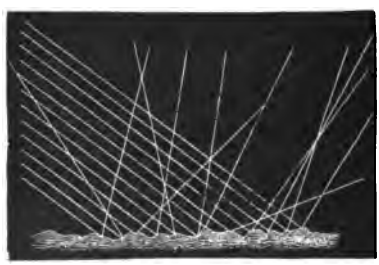


FIG. 16.—This is the way that most objects scatter the light, and thus enable us to see our way about.

I should like if possible, before closing the lesson, to please Louisa, by way of showing my appreciation of her question, and at the same time to prove to all of you, that

we failed to get an image on the paper because of its *rough surface* alone, not from the fact that it was *paper*, rather than some other substance. Let me try. Here is a letter which came this morning through the post. We will use this blank leaf. The paper is extra good—hot pressed—very highly polished. Now, Louisa, by holding the paper very close to the candle flame, and looking in a

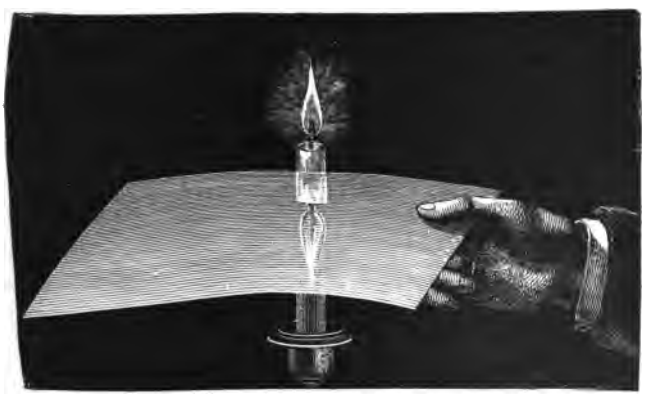


FIG. 17.—On holding the glossy paper very much aslant, we see an image of the candle.

slanting direction along the paper, I can see an image of the candle and flame (Fig. 17). Come here. Yes, you see it. The others may try it when dismissed.

Home Experiments

9. Try to find a piece of thick glass at home; if you can't get anything better, a bottle or tumbler with a flat thick bottom will do. Put it on some print and read through it. Notice how the letters are moved out of their places when seen through the glass (unless your eye is exactly *over* the letters you are reading).

10. Here are some little silvered discs, which I bought for you the other day. Take care of them, you will find them very useful in our experiments. Perhaps you may have seen them before on "regalia," *i.e.* those fancy aprons and sashes which Good Templars, Freemasons, Foresters, and others wear. They are sold at 3d. per ounce, and are so very light that I think an ounce will supply you all. I shall give you an amusing experiment to-night. Little boys are very fond of playing at "Doctor." Perhaps some of you can tell me how often your pulse ought to beat in a minute? You cannot. Well, you shall tell me to-morrow. Place your finger on your wrist a little below your thumb and find your pulse. Take this little disc and fix it on that spot with a bit of wax (boys always have something of the kind about them). Hold the mirror in the sunbeam or in gaslight; you may then watch the reflected beam dance backwards and forwards on the ceiling in a very funny way. If you laugh at the curious sight, your pulse will beat faster and the image on the wall will dance faster still.

Yes, it is quite true, and that I can easily show you. You see the table knife? "Yes." The blade is very bright—one side has the maker's name engraved upon it, you observe. That side is now opposite to you. I turn it slowly round, holding it vertically. When the maker's name appears before you again, I shall have turned the knife once round. Do you agree to that? "Yes." When the opposite side of the blade faces you I shall have turned the knife only half round. I will now show you that while our knife-mirror turns once round, the flash of light reflected from it moves twice round this room. If I turn the knife half round the sunbeam travels once round the room, coming back to the place whence it started. See, I pull down the blind and admit a sunbeam on to the knife-blade,

which I rest on the table. Watch the sunbeam dance round the room! Now look at the knife! The back of the knife is before you.

When you become excited your pulse beats faster than before and carries the little mirror with it. The reflected sunbeam dances twice as fast as the mirror. Try it for yourselves.

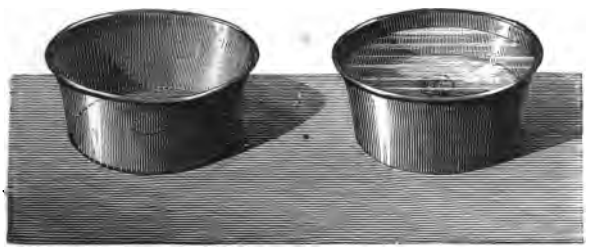
CHAPTER VI

THE BROKEN OAR

WHEN I was at Southport in the holidays, I took a little child out for a row. As she had never been in a little boat before, I was doubtful whether she would enjoy the sail. After a word of explanation, Ada took the cords in hand and steered away like a born sailor. Suddenly she cried out, "Oh, look! you've broken the oar—what shall we do?" I smiled, and held up the oar for her to look at. She said in a puzzled way, "Well, I thought it was broken." As I dipped the oar again, Ada called out excitedly, "There, it *is* broken!" I held it up for inspection as before. She seemed even more puzzled. Still keeping her eyes fixed on the oar, she exclaimed, "Look there again! How is it?" Now, I cannot take all you little folks to Southport. I wish I could! but fortunately that is not at all necessary in order to answer little Ada's question.

I will put this teaspoon in a glass of water. Is it broken? It looks as if it were! Did you bend it, Jim? "No." Well, look if it is not bent where it dips in the water. We will take it out again and examine it. It seems to be all right now! Lend me that flat ruler, Mary; be sure it is quite straight. The ruler is bent too! Where is it bent? Just where it touches the water, you say. It looks as if it

were broken. If you have not rowed a boat yourself, you have most likely been in one or at least have watched others. Did you never dip the end of a stick in pond or lake? If you pass a pond on your way home from school, you might try it. The stick will look as if it were broken. This appearance is called Refraction, or breaking. I



1. 2.

FIG. 18.—1. *Teacher*—"Keep your eye on the rim while I very gently pour in some water."

2. *Alfred*—"The penny seems to be rising out of its place, and moving forwards opposite to me. Now I see all of it quite plainly."

write the word on the board. What you see in the water is not the stick itself, but an image of the stick formed at that place.

Alfred, I will put a penny in this empty basin (Fig. 18). Come and look at it. Now stand farther back until you see only a bit of the rim. Stand still just where you are now, keep your eye on the rim, while I very gently pour in some water without disturbing the penny. What do you see? "The penny seems to be rising out of its place and moving forwards opposite to me. Now I see all of it quite plainly." That is because the rays of light from the penny are bent out of their path, just as in the case of the ruler or the teaspoon.

I will place the basin on the floor in front of the class and repeat the experiment for those who are near. Look!

I will draw on the board just what you see. You will ea be able to make these two experiments at home for yo selves. By using a penny squirt gently, you may ma the coin vanish and come back as often as you plea

FIG. 19.—The bottom of the lake appears to rise up from *o* to *o'*. "A pond that looks only three feet deep is really four feet deep."

Perhaps you may think, Alfred, that the penny does r up, but surely the bottom of the basin would not rise up t as it seems to do. No, it is but an image that you see.

The bottom of a lake too appears to rise in the same wa Water never looks as deep as it really is. Remember t when you go to swim. A pond that looks only three f

deep is really four feet deep. You may always be sure that water is a third deeper than it appears.

Here is an ordinary physic bottle with flat sides (Fig. 20). I have chosen the largest that I could find. Out of the centre of a piece of paper which covers one face of the bottle, I have cut a circle. All the rest of the bottle should be covered with black paper. I have ruled a horizontal and a perpendicular line in ink upon this glass circle, dividing it into four equal parts. The side of the bottle has two very narrow slits, almost from side to side, one just above the top of the circle, the other just where a line continued from the figure eight on our imaginary clock-face would touch the side. These are covered till wanted. I fill the bottle with water as far as the horizontal line in the centre of the circle, and put in two or three drops of milk. Now lowering the blind, I admit a sunbeam and reflect it at right angles by means of a mirror, so as to fall straight down through the neck of the bottle along the vertical line. A very little smoke from smouldering paper

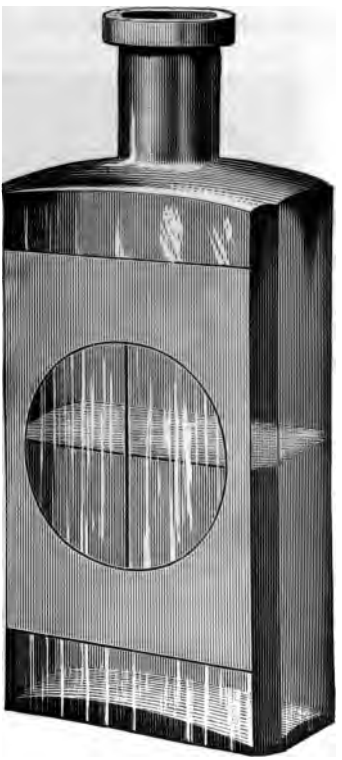


FIG. 20.—REFRACTION BOTTLE.

will reveal the track of the beam in air,—too much would scatter the light. The beam continues along the inked line, does it not?

Now I arrange the slit (D) and mirror (B) so as to send a reflected beam (C) to enter the water at the point where

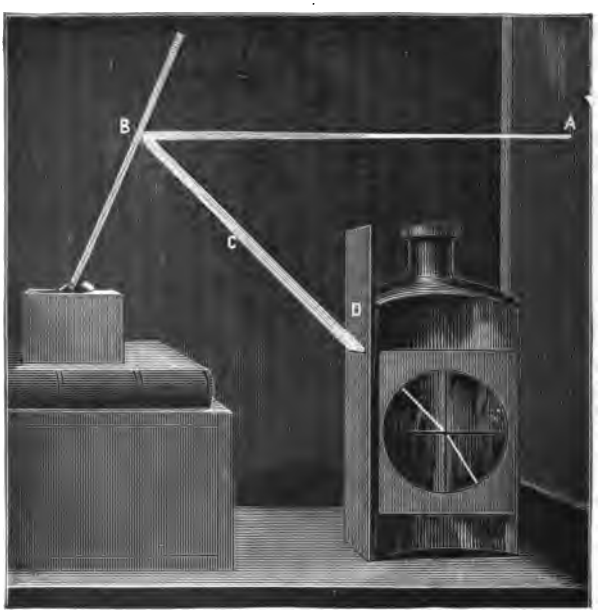


FIG. 21.—The beam appears to break on entering the water. The portion in the water is more *upright*.

the horizontal and perpendicular lines meet. In passing through the water the beam is bent nearer to the perpendicular line. We mark in red where the ray cuts the circumference of the circle both above and beneath the water (Fig. 21).

I have performed the experiment in this simple way to

show you how you may do the same at home, but I will now let you see how a better cell than this is made.

Near the shoulder of the bottle I tie round this piece of wool which has been soaked in turpentine. In making a cell like mine you must be careful that the wool makes a horizontal line round the bottle, and be sure that no turpentine is smeared on the glass; then light the wool. See, the flame travels round wherever the wool is and cracks the glass; the top has come off in a piece. The top of the cell is sharp too, and would do with rubbing down carefully on a stone or emery cloth. Here is a square of black paper. In the centre of the paper a circle has been cut out. I fix this label on the lower half of the cell's broad face, which it just covers. I cover one narrow side with white paper, the opposite side is uncovered. All the rest of the bottle except the circle ought to be covered with black. Does it not look like a little clock? I shall draw a line in ink from the 12 to the 6 and from the 3 to the 9 on our imaginary clock-face to help us in our measurements. Now our cell is ready we have filled it with water up to the inked line. We had better put a black card or a slate under the cell.[1] This black card in my hand is 6 or 8 inches long and wider than the bottle. Near one end of it is a very narrow slit ($\frac{1}{25}$ inch), which I can slide over the top of the cell into any position. Through the hole in the blind I admit a beam, and placing the slit exactly on the centre of the cell, I direct it by means of the hand-mirror along the vertical standing for 6 o'clock. Some of the light line is inside the cell, some is outside. Our clock points to 6 prompt! Sliding the cover, so, I admit the beam from 11 on our imaginary clock-face to the centre

[1] If the cell is not made before the children, let them be told how it is made.

where the ink-lines cross. Every beam must go through that point. Instead of going straight through from 1 to 7, the beam appears to break on entering the water. We will mark in green on the circle both where it enters the cell and where it leaves it. Compare it with the index-beam outside the cell. Sliding the slit a little farther on, we send another beam through the centre and mark in red

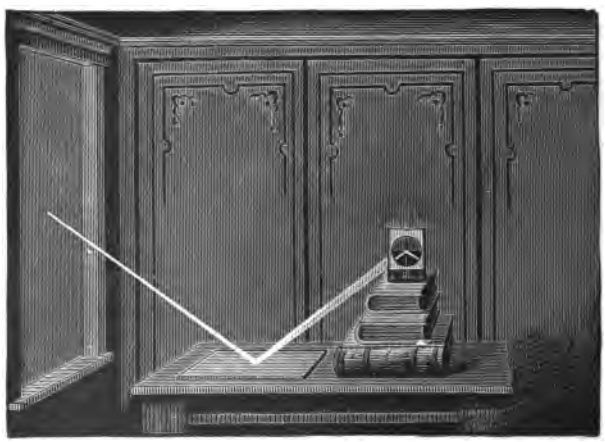


FIG. 22.—TOTAL INTERNAL REFLECTION. When *very* slanting rays enter the water, they do not pass out at all, but are entirely bent back into the water on touching the mirror-like (under) surface.

where it enters and where it leaves the cell. Moving the slit a little further we mark in blue—and still a little further in yellow. Now I continue down the side of the bottle. We have now come to a point *where the ray of light does not get out of the water at all*, but is reflected from the under surface of the water as though it were a mirror laid face downwards. Perhaps the easiest way for you to do this is to lay the mirror flat on the table and raise the cell (Fig. 22). Now we will wind up the blind and think about this.

With a slip of paper having a straight edge I measure on the face of the bottle the distance horizontally from the upper red mark to the Normal or perpendicular. I tear off the remainder, and fold the exact measure in two. I fold again and show you my measure divided into quarters. Now I measure from the lower red point to the normal, and find that the distance is just three divisions of the slip, *i.e.* three-quarters of the former. So that the beam in passing from the air into the water has moved one-quarter of the distance closer to the perpendicular line. We will measure the distance of yellow points from the normal also. We find the same rule to hold good, viz. that the beam on entering the water moves closer to the normal. When it leaves the water the distance from the normal is just three-quarters of its distance on entering from the air. Now take the blue points in the same way and measure them. Here again *the water measure is three divisions; the air measure is four of those divisions.* Next take the points marked green; these are both in water. Measure with a strip of paper as before. We find that they are *both equal.* Here we have reflection as from a mirror. But where is the mirror, you ask? You remember in your home experiment you put a coin, a pebble, a teaspoon, etc., in a glass of water, and holding the tumbler above the level of your eye looked upwards through the water to the surface? On the surface of the water seen from beneath were imaged all the objects lying at the bottom of the glass more brightly than in a mirror. Here, too, our little beam has been thrown upon that water mirror, and is reflected according to the rule or *law* not of *refraction*, but of *Reflection*, viz. *the angles on each side of the Normal are the same.* Or, The angle of incidence (falling-on) is equal to the angle of reflection (bending-back). (See also Fig. 5, where the angle ADC = the angle ADB.)

The law of *refraction* is not so intelligible in words, but so long as you fully understand it practically, that signifies little. Flat glass influences a ray of light in the same way that water does—also unsteady air and many other things;

FIG. 23.—PULSOMETER.

so that, strange as it may seem, we never see anything in its true place; the trembling air comes between ourselves and the sun, moon, and stars, and even the glass of the shop window comes between you and the cakes and nuts.

Kathie Russell, who was unable to be with us when I

distributed the pulse-mirrors, has just asked me for one. I am sorry that I have none here, Kathie. But you shall see the experiment nevertheless. I fasten a small mirror on my wrist. This indiarubber band will hold it securely, and at the same time will allow it to respond to the jerks of the pulse. Now, on lowering the blind, the spot of light dances rapidly to and fro on the ceiling! How very funny! Can you count?

Home Experiment

11. Robert has been showing me a little globe filled with water. He tells me he bought it at the toy-shop for a penny. You will find one very useful in our experiments. Those of you who can get one, please do so. To-morrow morning you may try an experiment which will help you to understand the Rainbow.

Turn your back to the sun, and holding the globe high above your head look up at it. At a certain height red light will be sent (refracted and reflected) to your eye. Then very slowly lowering it, orange light will take the place of the red. A little lower will give yellow light; lower still, green; then blue; then violet. If you make the experiment slowly, you will see these colours in the order named. You can do the same with the water-bottle used on the dinner-table; but in that case you had better not hold it up—it is too heavy. Put it near the edge of the table and kneel down; when you see the red light, gradually raise your head instead of lowering the globe.

CHAPTER VII

THE RAINBOW

YOUR home experiment with the water-bottle has, I am pleased to see, led some of you to invest a penny in the glass globe sold in the toy-shops as a "reading-glass," of which we spoke before. You will find it very useful in many experiments. You say that you at first held the globe as high as possible and looked up into it, and gradually lowered it. The first colour you saw in it as you stood with your back to the sun was red, which appeared at a certain height. Then, as you very slowly lowered it, the red light was exchanged for orange; a little lower the orange gave place to yellow, the yellow to green, the green to blue, and so on in succession to violet. To make quite sure that you all shall have seen that experiment before we proceed, I wish you to stand against the window and look into the water-bottle, which I have hung up from the top cross-bar of the easel, opposite to the hole in the blind. Walk from the blind towards the water-bottle until you see the red light coming from the bottom. Then stand still. Now you all see the violet light. Instead of my raising the globe, you may walk a little nearer, and stand when you see the indigo. Then, by slowly continuing to near the globe, you will see in succession, blue,

een, yellow, orange, and red. Now that you see the red ght, stand still. Now move slowly on. What kind of ght do you see? "It's all dark." Move on another pace. ow you see red light again, you say, but this time it is oming from the *top* of the bottle. What light do you see ow? "Orange." Now if you move on very slowly, you ill see yellow, green, blue, indigo, and violet rays, each oming in turn from the top of the globe.

Here we shall make a very similar experiment, which ou can also try at home with your little globes, if you ake particular notice how we arrange matters, which for his reason I shall make as simple as possible.

This is an ordinary bottle with a cork in it, as you see. I shall use it for a stand, and to make it very steady shall fill it with water. You will find this stand very useful and easily obtained. You see also that I have bored a hole in the cork.

Here is a small, perfectly round flask ($1\frac{1}{2}$ to 2 inches in diameter) with a long neck. It is filled with filtered salt-water. We will push the neck of the flask in the hole that I showed you in this cork.

Now for this experiment a strong beam of sunshine is needed. Some of you boys in your target practice have found out that the sun does not shine always on the same spot, so that if we make a hole in the blind the sun won't shine through it very long. Sir Isaac Newton, one of the greatest men who ever lived, noticed this as a boy. I shall tell you something about him next day. To-day I shall only say that he used to go into the yard when the sun was shining, and mark on the walls of the house and buildings how far the sunshine came each hour or half-hour in the day, and drive a nail in that place. He did this for several years, and the country people used to come

and look at "Isaac's dials" when they wanted to know the time. Don't you think you could make a dial if I were to allow you to put pins in the window-frame? Where is the sun shining through just now? Let us take particular

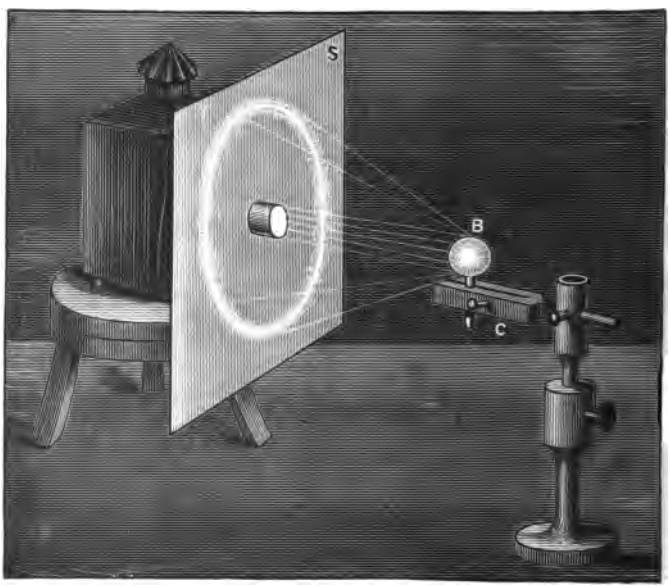


FIG. 24.—RAINBOW EXPERIMENT WITH THE LANTERN. The bulb (B) is clamped in a Bunsen-holder (C). The cardboard screen (S) is fitted on to the nozzle of the lantern to catch the rays reflected from the bulb. The lantern is adjusted so as to send a parallel beam on to the bulb.

notice. I lower the blind, and hold a card behind and a penny in front.[1] If I cut round the penny with a sharp pen-knife, I shall make a clear-cut hole almost the diameter of the globe. This large sheet of white paper also has a similar hole in the centre. I hang it to the blind by means of this piece of gummed paper, so that the holes

[1] The hole must be of the same diameter as the globe used.

shall cover each other. Now I bring the bulb near, *i.e.* within half the length of the square of white paper which serves as a screen (S, Fig. 24; see also Fig. 33). We have at this distance a complete rainbow circle. If the direct sunshine is too bright in your face, for you to see the circle, screen it off with your slate, Mary. I need scarcely tell you that this is the real rainbow reversed. · Any spot where red appears on the screen means that if your eye were there looking into the glass bulb you would see red light. If you placed your eye anywhere in the path of the yellow rays, you would see yellow in the bulb, and so on for the other colours.

Harry, you look amazed to think that we can bring rainbows into school! Let us try to understand what we see before us. We will imagine that we have caught a raindrop—a very large one, so that we can almost see what is going on inside.

Let this bulb represent the raindrop. I will draw its picture on the blackboard; but before I raise the blind, let us try to make out, by the help of the smoke from this paper, exactly what takes place. Look at the bulb. See how it glistens! Some of the rays are reflected from it at once when they touch it, that is why it shines so. But these rays do not make the rainbow. You observe a number of parallel rays meeting the drop. You can follow distinctly the path of the central ones, for they pass straight through the drop, and cause that bright spot of light that shone into Mary Mackenzie's eyes until she shut it off with her slate. These rays do not make the rainbow either. No! The rays which make the rainbow enter the drop near either the top or the bottom (Fig. 25). Let us trace the course of those rays falling on the drop near its top. Most of them pass inside the drop, and wend their way through the water to the middle of the opposite wall, so to speak.

How is that? You are right, Lily; they are refracted in passing through the water. Now this wall is a curved mirror; some of the rays pass out through it, but the rest are reflected to the lower front of the drop. With a very little smoke from this paper you may see the coloured rays on their way to the screen. Do you see them?

But even here, not all the light passes into the air, for the whole of the inner surface of the drop forms one large

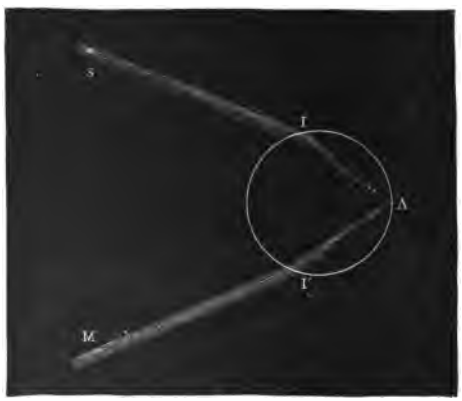


FIG. 25.—MAGNIFIED RAINDROP, SHOWING THE PATH OF THE RAYS WHICH MAKE THE PRIMARY BOW. Rays of light (SI) fall on the drop near the top at I and are refracted to the back of the drop (A). At A they are reflected to I', where they pass out.

curved mirror, and wherever light falls on this mirror, *some* portion of it is sent back across the water to another part of the same, a little light escaping into the air at each reflection.

From this you will see that there are really many rainbows in the sky. But, as a rule, we do not see more than two. The primary bow is formed by rays which have entered the raindrop near the top, and after one reflection at the bottom, reach our eyes from the lower front of the drop. This is the brightest bow.

The secondary bow found outside the first is from drops much higher up in the sky (Fig. 26). It is much fainter, because the rays have been reflected twice within the drop. Here the rays enter at the bottom, and come out at the top. The other bows are still fainter, and being nearer to the sun, are lost in his splendour.

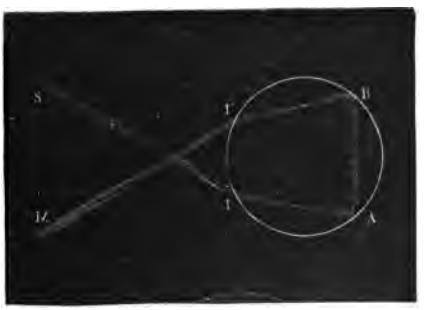


FIG. 26.—MAGNIFIED RAINDROP, SHOWING THE PATH OF THE RAYS WHICH MAKE THE SECONDARY BOW. Rays of light (SI) fall on the drop near the bottom (at I), and are refracted to A; from A they are reflected to B, from B they are reflected to I', where they pass out in the direction I' M, crossing the incoming rays.

I daresay you know as well as I do where to look for a rainbow. Eliza says, "In a sunshiny shower." Yes; we must have the sun shining upon the raindrops to make that beautiful coloured arch in the sky.

I daresay you can tell me whereabouts in the sky we should look for the rainbow. "Opposite the sun," Mary says, and that is right.

Longfellow in that beautiful poem of his, which we have read together, about the rain—

> Follows the water-drops
> . . . . .
> And sees them, when the rain is done,
> On the bridge of colours seven
> Climbing up once more to heaven,
> Opposite the setting sun.

Why opposite the setting sun?

The higher the rainbow is in the sky, the more we can see of the circle. It is seen at the highest when the sun is lowest, *i.e.* at sunrise or sunset. As the sun rises in the sky the arch grows less, and entirely disappears when he is above a certain point,[1] so that we never see a rainbow at noon—only in the morning or evening. Very rarely, indeed, you may see a rainbow at midnight, when a full moon is low in the south; and sometimes the image of the sun reflected in still water causes a rainbow.

But Lucy tells me that a rainbow is not a complete circle, such as we have on the screen. Lucy, if you wish to see a rainbow properly, mount as high as you can. If you go up into a tower, you may sometimes see a rainbow which you cannot see from the ground. While from the top of the ship's mast, could you climb up as the sailors do, you would be able to see almost a circle at times. The complete circle is seen from a balloon.

Our image on the screen really represents the second rainbow which is sometimes seen outside the first. The red circle is inside, and the violet is on the outside; while in the brightest bow these colours are reversed—the red band is outside and the violet inside.

Mary, have you brought your hoop to school to-day? You have, Maria? Bring it. What shape is it? Round, you say. Let us see! Take it quite to the other end of the room, and rear it against the wall opposite to us. Is it round? Now turn it a little towards the window; now a little more. What shape does it appear now? "Oval." Turn a little more—a little more—now we see only the edge.

I daresay some of you little folks say to a companion, "I saw the rainbow." "I saw it too," says he or she. But did they really see *it*; that is, the very same rainbow that

[1] 42 degrees above the horizon.

you saw? No! every one sees a rainbow of his own. If there were but *one* rainbow, we should see an oval or an edge, or some other form, according to where we stood, and we know that this is not the case.

We have not yet learned *how* these beautiful coloured lights come out of the sunshine. We will leave that for another day. Tell me what colours you distinctly see reflected on the screen, beginning from the inner circle. "Red, orange, green, blue, violet." Between the blue and the violet we have a very deep shade of blue called indigo. Now say them again, and put that in. But are these colours separate and distinct, as seven ribbons, placed side by side, would be? There are an infinite number, that means "no end of numbers," of colours before us, all blending imperceptibly into each other, till it would be hard indeed to say the exact point at which any one colour left off and the next began. We say that each colour has a variety of *shades*, or *slight differences*, that enable us to distinguish them.

Notice, too, the position of the colours. Orange is between — and —? Green is between — and —? Indigo is between — and —? Yellow is between — and —? Although we have produced these coloured circles on the screen, in order that you might see what the rainbow looks like, please don't run away with the idea that Nature makes her rainbows out of *one drop*. Nor does Nature project her rainbows on a screen, though you might be inclined to think so. No! the coloured light comes straight out of the drops into our eyes. I think the dullest of us has learned from our experiments that we can see light of only one colour in a bulb, and that to see any other colour we must move either the bulb or our eye. To see two colours at the same moment, we must have more than one raindrop.

Observe that although *each* raindrop reflects light of every colour, only one colour from each drop finds its way into the pupil of the man's eye; the others are either too high or too low. Thus from the upper drop the violet, indigo, blue, green, yellow, and orange rays are above him; the red only enters the eye. In like manner, in the lower drop, the violet only enters the eye; the other rays fall beneath. From drops between these two he will receive respectively orange, yellow, blue, green, and indigo rays. Notice the angle (red 42°, violet 40°) made with the horizon; this is half the angle of the cone, because the cone gave a *complete* circle.

FIG. 27.—THE RAINBOW, SHOWING THE HIGHEST AND LOWEST DROPS IN THE ARCH HIGHLY MAGNIFIED.

I daresay you have watched the grocer take up the corner of a piece paper between the finger and thumb of his left hand, and twirl it round, so, with his right? Into this little *cone* he puts small quantities of coffee or spices, as the case may be. I am not going to do that. Nor shall I give it the little twist at the end which he so prides himself in. You see that by turning the paper round the thumb four or five times, the mouth, where the spice is put in, becomes much less wide. Can you do that? There is paper in front of you. The narrow end must be very little larger than a pinhole. Take the cone up in your left hand, so, and look at this mark on the board. I want you to imagine that it is raining in this room, and further, that your cone extends up to the blackboard, which is the limit of the shower. Your cone is full of raindrops. If you find that hard to imagine, fancy that it is full of colourless transparent glass balls about the size of peas. Now if your cone is just wide enough to admit your thumb, we will begin. Look *through* the raindrops at the blackboard. The sun is behind you. White light is reflected into your eye not from the board, as it might seem, but from the raindrops. I will represent a little hazy cloud on the board; it is not very brilliant. Do you see it through the cone? Now, keeping the narrow end of the cone tightly grasped between the thumb and first finger, allow the others a little freedom. There, the *base* or mouth of the cone has opened wider. Look now through the raindrops. A violet circle surrounding the white has also come into view. You see it on the board. Yes; but remember the *violet light* is not on the board, but is reflected into your eye *from every raindrop that rests against the wall of your cone.*

Now please loosen your hold a very little. The cone grows wider in immediate response! Encircling the violet

band, you now see also one of indigo, which I have just drawn. These indigo rays are reflected from each drop which touches the wall of this larger cone. Relaxing your grasp still a little more, you form a still larger cone, which brings into view a blue band outside the others. If you see beyond the blue band your cone is too wide, and you will please draw it in a little. Now while I make the green circle, adjust your cone once more. You see circles of violet, indigo, blue, and green; the green rays are reflected from the raindrops against the walls of the tunnel as before. I take up the yellow chalk and make a circle. I see you are ready; be very exact; you must not see beyond the yellow, but make sure you see all of that and its enclosure. Now for the orange circle, make your cones ready! This red circle marks the limit of the bow. Your cone shows you a complete rainbow (Fig. 27).

Now, children, what next? Percy has put his cone down, I see; but Donald is evidently waiting. What do you expect, Donald? "The secondary bow begins with red." But is there not something between? "I didn't see anything, teacher." Had you not to walk a little way just now before you saw the second red band. "Yes; and then the red light came from the *top* of the drop." You are right; but perhaps you did not notice that the space between the bows was very dark. It would be a *black* band, but for the light that glistens on the outside of each drop; no light whatever that has travelled *through the drops* reaches your eye. So that I shall leave a space on the blackboard between the red bands. Now when your cones just take in the red of the secondary bow, we will go on to the next band, which is —? Orange—right, Jessie. The next is —? (yellow). The next is —? (green). I shall go right on to violet, for I see that we are keeping together nicely.

Now I believe you have a very different idea of what a rainbow is than when you came to school this morning! Next time you see a rainbow, treat it in this manner. "Will it be just the same as that on the board?" No, Frank, for ours is a model rainbow. In the real rainbow the colours sometimes repeat themselves in a very puzzling way, perhaps something like this—red, blue; red, blue; red, green; red, yellow, green, violet; red, yellow, green, blue, violet, and so on. I can't tell you at present *why* this is—it is too hard for you to understand; but we shall learn something more about it by and by, when we look at soap-bubbles. What I want you to notice now is that the bows are separated by the dark band. Many people talk about seeing so many rainbows, that I rather suspect they count up the red bands, and consider that the space from one red to the next red is a rainbow.

But we have been picturing the raindrops as standing still. "I don't know how they get through the paper." It is not necessary that they should, Nellie! The paper cone has helped us to separate those raindrops that make the rainbow from their neighbours which do not. But the raindrops do their work just the same, if you imagine the paper to be there, or find some other cone that will allow them to pass through. The cone was to help *you*.

The drops do not stand still, but as they move down, others slip into their places, so exceedingly quickly that there are always raindrops in the right places carrying on the work. That is to say, as far as the shower extends; but if rain only comes down on our right hand or on our left, we see merely a part of the arch. The same thing occurs if there is a patch of blue sky beyond. To see a brilliant rainbow we want a dark cloud for a background and "heavy drops" of rain; for the larger the drops are,

the brighter is the rainbow. If we could reduce the size of the sun to a mere point, the colour-bands would be still brighter and more distinct.

FIG. 28.—RAINBOWS IN NIAGARA FALLS. The Cavern of the Winds below the Falls

You will also see these rainbow colours in water-falls (Fig. 28), fountains, and in the drops of dew that glisten on spider-webs in the early morning of an autumn day.

If you have an opportunity of trying the fountain yourself —you had better ask permission first—turn the water-tap on

a little, and squirt with your thumb a very fine jet of water upwards against the inside of a spoon. Bright sunshine and fine drops are needed, though they need not be drops of *water*.

"Please, teacher, I thought you said we could not see a rainbow except in the morning or evening. How is it that we can have a rainbow in school in the afternoon at two o'clock?"

That is a very sensible question, Walter. I'm afraid I can't make you understand fully till you've learned a little more. *It depends on the slanting of the sunbeams.* Look at the beam we are working with; its direction has been altered by Harry Stevenson, who is in the playground, mirror in hand, reflecting the beam *horizontally* into the room. Now I will make another hole in the blind away from the first, and allow a sunbeam to come in naturally, without interfering with its freedom in any way. I think you will find that it slants very much.

I really don't expect you to understand why the sunbeams must meet the raindrops in a nearly horizontal direction to make a rainbow. But perhaps I can give you an amusing explanation that will help you along for the present. Imagine the sun and the rainbow to be playing see-saw. The plank must go through your eye, by the way—but that won't hurt, as it is only a sunbeam. The sun is at one end, the rainbow at the other. When the sun is down, the rainbow is up; then we see the most of it, as at morning and evening. When the sun is high up in the sky, the rainbow is down, down out of sight. This is the case at noon, for then the sun is at its highest point in the sky. Indeed, it is the case before the sun has risen nearly so high as he is at noon.

You will not see rainbows either in showers or in foun-

The primary bow was the lowest (showing violet underneath). The secondary bow was immediately above it, and parallel with it; its colours were reversed (showing violet on the top). The third and highest bow, starting from the extremities of the first, was a primary bow, formed by the sun's image reflected in a river.

FIG. 29.—A TRIPLE RAINBOW.

tains unless you turn your back to the sun. Remember also that the centre of the sun, your eye, and the centre of the rainbow are to be in the same straight line.

Home Experiments

12. (*a*) Take these two pieces of coloured paper, one in each hand, and go into the cellar or some dark room, and tell me what colour each is, there. I shall give out papers of all colours to the class. Write down on your slate first which you carry in the right hand and which you take in your left, so as to make no mistake.

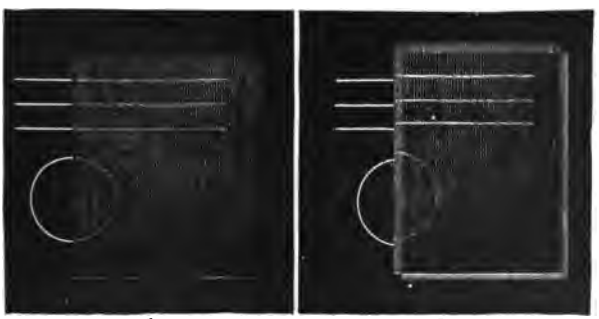
(*b*) Fill a tall glass bottle or jar with water, and put it on the table. Place a lighted candle at the same height, but three or four yards away. Now walk alongside the light and the bottle, keeping your eye on the same level. You will see bundles of coloured rays issuing from the side of the bottle, from violet to red; and by continuing your walk you will meet with the second series, from red to violet, proceeding from the other side of the bottle.

CHAPTER VIII

THE SPECTRUM

THE other day, as I sat reading a book by the window, a gleam of sunshine suddenly burst forth, and wrapped *me* and my book round and round as with a warm invisible cloak. Some people would have got up and gone away, as though the sunbeam had done them some harm; but I sat there enjoying it, and gazing down upon my book I found the page lit up with scores of little spots dotted all over the page like so many little rainbows. I could not help thinking how kind the sun is. I rose and tried to find out whence the spots were. The spots came too. And then I caught sight of what seemed to be the cause. I put my hand to my brooch and the spots vanished. I withdrew my hand and the spots came back again. The mystery was solved. And as this sight gave me so much pleasure, I will repeat it for you. Then we will try to account for it. We must go back to our lesson on refraction. You remember that we sent several sunbeams from the air into water, and discovered that the breaking of the line followed a certain rule or law, and at home you found on laying a piece of flat glass upon your book that the letters, when seen through it, seemed moved from their proper positions. I have here an extra thick piece of glass, which shows this

ery plainly. You may open your book anywhere, and place he glass upon it, or you may lay it on this paper (Fig. 30). ass it round the class, John; but first let me show you mething further. I hold the glass at some little distance om the book, and the letters are still further displaced. he rays of light which come up from the printed page to



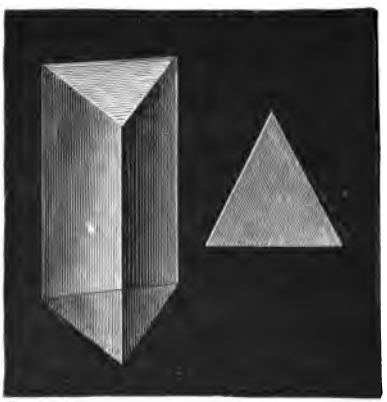
1. 2.

FIG. 30.—LINES AND CIRCLES VIEWED THROUGH PLATE-GLASS. The glass is placed so as to cover a part of the lines.

1. When the eye is brought exactly over the lines they appear to be straight. | 2. If the eye move from this position the lines seem broken at the edge of the glass.

the eye pass first *through the air* to the glass, next *through the glass*, then out of the glass *into the air again*, before reaching my eye. When a piece of glass is not perfectly flat, the light lines are bent still more out of their course. This glass is raised in the centre like a little mound. It is exactly the shape of a lentil; we call it a "lens," which means a lentil. Which of you has bought lentils for mother to put in the soup? Ever so many of you, and the rest of you have seen them in the grocers' windows. The lentils the grocer sells are usually only halves, and we have lenses of that shape too. Some lenses are like this watch-glass in shape. One side bulges out and the other is hollow. Ask your father or grandfather to show you his spectacles,

if he has any, and you will find out many curious things for yourselves. But here is a piece of glass of a different shape again. It is like the stones in my brooch, and gives the colours of the rainbow. It is a button from one of those rather old-fashioned but very pretty ornaments called lustres, and here is one of the long drops which so often come off (Fig. 31). I begged this of a lady, who said it was "no good." Let us see if it is no good! First let us have a look at it. Pass it round the class, Harry.



1. 2.

FIG. 31.—1. A PRISM. 2. END VIEW OF PRISM.

How many sides has it? Of what form is the bottom and the top? (Δ) Pass round this prism and the flat glass. While you do so, I will tell you about a little boy who grew up to be one of the most wonderful men that ever lived. Two hundred and fifty years ago, in a Lincolnshire village, a little baby was born. He was so very small and delicate that his mother used to say she could put him into a quart mug. His companions at school at first looked upon him as idle and inattentive to the lessons; and I daresay they were very dry in those days to a boy like *Isaac Newton*, and not at all to his mind. Nor did he care much for the playground either. While the other boys romped out of doors, Isaac was making all sorts of mechanical toys. He made a clock that went by water, a mill turned by a mouse, a carriage moved by the

person who sat in it, and all kinds of curious contrivances. He was a great boy for kites too; he took much pains to find out exactly the best shapes and proportions for flying, and the exact spot where the string should go. He made lanterns of crimped paper, and put bits of candle in, so that he could see his way to school on dark winter mornings. At night he would fasten his lantern to the kite-tail. This frightened the country people, who mistook it for a comet. But you must not think that he continued to be a dunce at his lessons. No! One day the boy above him in the class kicked Isaac in the stomach, and hurt him badly. Isaac was very much ashamed of him, and determined to take his place. He soon rose to the position of head boy in the school, and kept there.

Now if you have all seen through the glasses, we will continue our lesson. I have not time to tell you more about Newton to-day, nor of the many puzzling questions he made clear before he became a young man, and performed this very experiment which we shall make in the same way. He bored a hole in the shutter and admitted a sunbeam, and held a prism like this, point downwards, in its path. You see the result. Directly the prism is placed in the beam the image of the sun suddenly rises from the floor, and is drawn out into a coloured band on the wall or screen. Closing up the round hole in the blind, we make a vertical slit almost an inch long, and as narrow as possible ($\frac{1}{25}$ to $\frac{1}{12}$ inch diameter). By turning the prism slowly round in the fingers, a certain position is found in which the band is brightest. I will show you again, for it is necessary for you to understand all the "ins and outs," so to speak, if you would perform these experiments yourselves, as you have done so far. Notice this time where the white light streams in. You do? Now I hold the prism with its sharpest edge parallel

with the slit—the image is gone far away. By moving the prism, I bring the coloured band back as near as possible to where the sunbeam fell at first. Can you do that? "Yes." (Although the glass has three edges, only one is used; the centre of the beam must pass straight through the two opposite faces that meet in that edge.)

Now let me recall to your mind the home experiment with the coloured papers. You all wondered so much that your paper was black as pitch in the cellar. I suppose if I were to tell you that the colour is not in your paper at all, you would be inclined to doubt that. I know it is very difficult to believe, nevertheless it is fact. The colour is *in the sunshine*, not in the paper. *The colour is sunshine* and nothing, nothing else.

You remember in one of our first lessons we learned that a mere thread-like line of light was a bundle of many rays; and we have seen how these rays are broken in passing through air into glass, and again broken in passing from the glass into air, as we saw in reading through the thick sheet of glass. But this had parallel faces. When the opposite faces *meet* at an angle, as they do here (prism), the rays are entirely loosed from the bundle, and each goes its own way (Fig. 32).

I want you to look well into that *spectrum*, as Newton called it when he saw it. The word means the same as "spectacle" or "appearance." I suppose however often one makes this experiment it never loses its fascination. I have known grown-up people wild with delight on first seeing it, and this feeling goes with us as our guide ever after in our experiments with sunshine.

The first thing that struck Newton, after his surprise on seeing colour, was that there should be a long band

instead of a round spot or image of the sun—a long band *with rounded* ends, like a sun drawn out endwise. After *trying various* ways to make this out, none of which supplied *the needed* explanation, he thought then that there

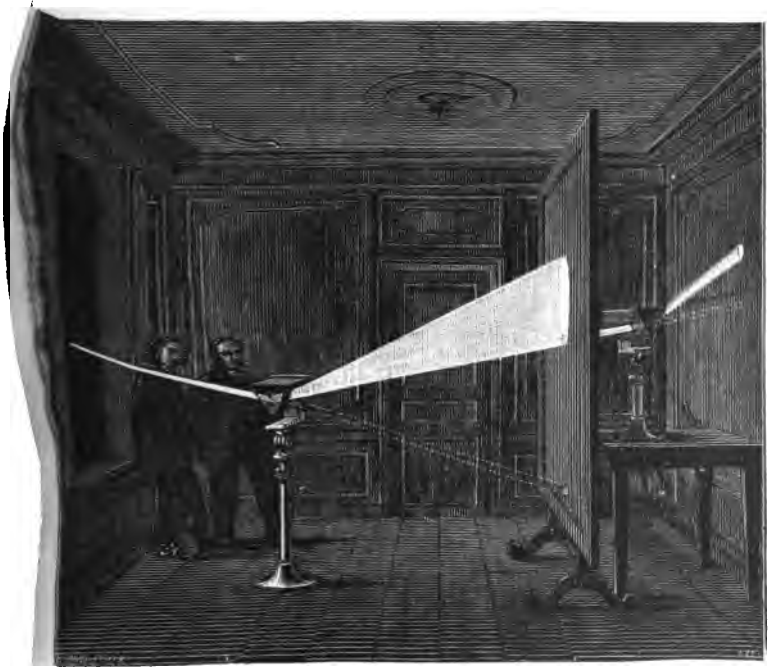


FIG. 32.—NEWTON'S SPECTRUM. Passing each colour through a second prism.

must be some difference in the colour-rays themselves that caused them to part company. If you will look at the rays as they pass from the prism to the screen, you will see that some of them go a nearer way to the screen than others; those that go straightest there are the — ones? those that are bent most are the — ones? I want you to take notice

how many millions of rays are there. No two of them are of exactly the same colour.

But Newton was not content yet. He must know if those colour-rays he saw could be separated still further apart; perhaps they might not be the simple colours

FIG. 33.—RAINBOW EXPERIMENT with the water-bottle held in the path of a sunbeam admitted through a hole in the shutter.

after all, but groups of colour-rays, of which he must see each separate member. Accordingly he made a small hole in the screen, and allowed a few red rays to pass through on to a second prism. The rays were *bent a little more* after passing through the second prism, but there was no other change—they were red rays still. Then the orange rays alone were made to pass through the hole and second prism, but they were orange still. Newton tried them

each in turn, from red to violet, and found that all of them were *simple* colours,—not made up of others, or *compound*, as we say—the red ones here, the violet ones there, like a family of children all running out of the same front door, in different directions, till stopped in this case by a wall (screen).

Now, if what I told you be true, namely, that sunshine is made up of rays of light of all colours, and that these rays, by being bent very much out of their original path, are entirely separated, we ought to be able to mix them up again into white light. That is easily done by passing them through a second prism reversed; but I can do so less perfectly thus. I reflect the spectrum on to the ceiling by holding this mirror between the prism and the screen. And now I shake the mirror very quickly too and fro. You see the rays on the ceiling mix up as I move the mirror. I cannot quite get rid of the coloured spots at the end, but you see that the middle is white. As I move the mirror backwards and forwards I have to change the direction at the end of each journey, just as the omnibuses have to turn round before they can go back, and in this way time is lost, so that I can't quite get rid of colour at the ends.

Our last sunshine story was about *Nature's Spectrum*, the Rainbow, in which raindrops play the part of prisms. I hope you will never forget it.

Home Experiments

13. Do you think you could make a refraction cell?

It is not necessary to take the neck off the bottle. It will do quite well if made like mine in other respects. In that case you admit the sunbeam from the side opposite to the one papered white (Fig. 20).

14. I should like you to make the rainbow experiment with either the penny bulb or the water-bottle. Look at this picture as a guide (Fig. 33).

CHAPTER IX

A COLOURED FAMILY AT HOME

OUR story to-day will begin where we left off. Our arrangement is the same as before. Last day I showed you how the rays after passing through the prism could be mingled together again by the mirror. Although this plan does not give us a white spot of light, I like it because it shows the mixing process. Now we shall have a better result. This globe of water will draw those spread-out rays close together. You see the spot of white light—the image of the sun on this screen? Now we have succeeded in showing that the prism and the globe act contrary to each other. The prism spreads out the sunbeam, making the colour-rays stand out side by side each in its own position. However often we separate a sunbeam in this way, we never find any ray out of its place, *e.g.* we never find green and orange, or indigo and red rays, side by side, scrambling to their places. The globe, on the contrary, draws these rays up into "close order," so that they shall take up as little room as possible and pass out through a very small opening, as it were.

Perhaps you may have seen something like this at the railway station. A train comes in and instantly the platform is filled with people, all in a hurry, and I am afraid

some may be pushing others to get on in front. The further up the platform the stream goes, the closer the people press. Perhaps now they have to pass down some steps or through a narrow winding passage. The crushing is terrible, increasing every moment, as little folks know, for they get the worst of it. At the end of the passage is a door, very likely only one side is open, as frequently

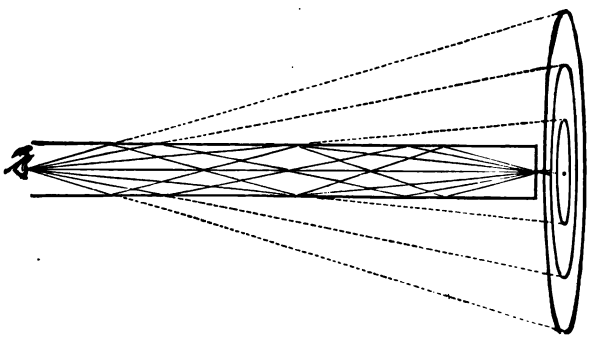


FIG. 34.—REFLECTION TUBE, showing how rays of light on coming through the hole (dot) are reflected from side to side of the tube. Trace one or two. The eye always refuses to follow out the zigzag course of rays, and only takes account of the *straight portion which enters the eye after the last bend. We see objects in the direction of these lines continued* (dotted lines). This explains why the eye sees circles much wider than the tube. Here is the *golden rule* of our subject.

happens. The crowd try to pass out of the door in the same numbers as they came down the passage, but they cannot. By this time the people behind have come up and are eagerly pressing forward, pushing them through. This, it seems to me, is a picture of the way in which those separated colour-rays from the prism there are being crushed in passing through the interior of that globe. Speaking of the railway station reminds me of that very busy time when one sees so many smiling faces looking from the train, and so many smiling faces too on the platform waiting

to catch the first glances of the sons and daughters, brothers and sisters, uncles and aunts, who are eagerly peering out of the carriage windows. Almost quicker than it takes to tell, everybody on the platform whirls off with some one else and a great quantity of luggage, and talks in very loud tones, trying to say everything at once, and running against porters and trucks. It is Christmas time. The children are home from school, the fathers and big brothers too have holidays. I dare not tell you all about this happy season. I should never finish. I will just remind you that in every house a great effort is made to gather all the family together, wheresoever they may be, that they may sit down together on Christmas day as if they had never left home. And this is the meaning of those meetings at the station. You will wonder what this has to do with our lesson. It seems to me, that in this sunbeam, we have represented a family gathering such as we have been picturing to ourselves. Every one is in his right place, as the spectrum shows us. There are the grave and serious red and orange rays that move with stately tread, and below them the elder sons and daughters, as we might fancy the many tints of yellow and green, down to the frolicsome boys and girls of blue, and frisky baby violet, the life and soul of the house, always performing gymnastics for the amusement of the company.

This sunbeam, then, this gathering of the rays of all colours into pure white light, represents the whole family at home.

What I want to show you is, that coloured light is due to the *absence* of some one or more members of this family. This is very important, and is easily proved without moving either prism or globe. The time has come for the happy gathering to separate. Little violet is the first to go.

How can we manage this? See, I receive the spectrum on this white card to be sure that all the rays are there. "Yes." Louisa, stand exactly behind that globe in the place of that screen. Now you will see the light fall upon

FIG. 35.—ZULU CHIEF.

her white pinafore when I allow the *all-coloured rays to* unite by withdrawing the card. Again I receive the spectrum on the card. This time I shall slide off all the coloured rays except the violet, which I shall hold back. Do you see any difference in Louisa's pinafore? Yes, it is slightly yellow, you say. Now I stop also blue and then

green. See, the pinafore becomes redder, now it is scarlet, now orange, now blood-red. Half the family have left the old home now. All the youngsters are gone.

Now I will go round to the other side of the spectrum with my card. Again the family is home—every member. Louisa's pinafore is white. The red rays are to leave home first this time, then orange, yellow, etc. Now watch the pinafore as it turns first pale blue, then bright green, ultramarine blue, indigo, and violet. This will finish our story for to-day. I must not tell you any more lest you forget these important lessons, which I shall write on the board.

1. *Whenever a beam of light passes through a transparent substance a spectrum is produced* (except when it passes through parallel sides).

2. *Sunshine is a mixture of rays of every colour and shade blended together.*

3. *When light is not white or all-coloured some colour-rays are missing.*

Home Experiments

15. Hold a lighted match before a mirror, look sideways into the glass. Describe what you see.

16. Find a tall round bottle. Take the bottom off. Paste black paper or cloth round the tube. Make a small round hole in a card and hold it against the wide end. Look through the neck of the tube at a candle or gas-flame, or out of the window. If you have nothing better, use a long tin canister. Take off the lid and paste a paper disc inside the lid. Put the lid on again, and make in it a clear-cut small round hole. Make a small hole in the other end for the eye. Do not blacken the tube inside; keep it bright as a reflector. Take the tube to the window and look through it (Fig. 34).

CHAPTER X

RAYS AND THEIR WAYS

LET me explain to you the experiment which gave you such surprise and delight at home. Some of you boys are becoming quite clever in describing on paper what you see, and two of you have made sketches. Your experiment was to light a match or taper, and hold it in front of the looking-glass, and then look sideways into the glass. A little boy tells me that he saw a whole army of lighted matches (Fig. 36). The first image was faint, the one immediately behind it was bright, and behind these in single file were a great procession of faint images. The more sideways he looked the more images he saw. Now let me tell you how this comes about, for no one has ventured any explanation. In front of each of you, on the desk, is a slip of plain glass. Take it up and tell me—can you see your face in it? No! Look again; look sideways into the glass. Now you see things almost as well as in a looking-glass. As I came to school this morning I saw one of the little girls before me, trying this very experiment in a shop window. For myself, I may say, that I have amused myself often in railway trains by observing in the window the images of my neighbours. The effect is very peculiar. There they are as real as life, and yet their bodies are quite

transparent. Railway trains pass through them at express speed; hedges, walls, mountains, sheep and cattle, smiling pasture fields, rivers, telegraph posts — all these pass through them, and yet the passengers seem to be unhurt.

I suppose you have all seen the back of a looking-glass. Quicksilver is put at the back of looking-glasses because it reflects so many rays—not only those which come from the sun, but those which come from your face. The sun's rays first play on your face, then dart off and strike the looking-glass, then they turn back and rush through the pupil of your eye to the back of it, and make an image on a screen there. The first image of your lighted match or taper was formed on the upper surface of the glass, therefore it was only faint. The second was formed on the silvered surface. The others were formed by reflections backwards and forwards from surface to surface. You will wonder what this has to do with our lesson. Let us see—

FIG. 36. — A WHOLE ARMY OF LIGHTED CANDLES. The first image is formed at the upper (unsilvered) surface of the glass. The *second* image is formed at the silvered surface (and is the *brightest* of the series). The third image is formed on upper surface. The fourth image is formed on the silvered surface, etc.

1. Sometimes, when we are at home, some naughty boys bang against the front door, and then rush off again. Do they not call this playing at "Black Rabbit"? I see you know all about it!

2. Or some boys may come to the front door and be "asked in" to stay a while.

3. I remember once the school in which I taught was near the top of a long street, and to get into the next street to a house, or to the school just opposite, where I had friends, I had to go all the way down our street and up the next. Very soon I came to know the neighbours, and they very kindly said, "You may come through our house, if you will." So I was very glad, and went straight through the hall and out at the front door into the green fields beyond to my friends' school.

Now there are three ways in which a ray of light may move.

1. It may strike an object and then dart off again, as though it were playing Black Rabbit. This is *Reflection*, or bending back.

2. Or it may push its way into the heart of the substance itself and stay there. It is then said to be *absorbed* or drunk up by the object, as blotting-paper drinks up ink or a sponge holds water. *Absorbed* is not at all a good word to apply to these rays, for we shall see that they are not drunk up as by a sponge; but no one knows *exactly* what goes on inside, for we lose trace of the rays.

3. Or it may pass right through, as I passed through that house. This is called *Transmission*, or sending across.

Now this is true of rays, but, as you know, a sunbeam is a bundle of such rays. Never is a sunbeam, even though it appears like a single fibre of silk, either all of it transmitted or all of it absorbed. The moment a sunbeam [1] touches an object some of its rays part company. I can easily show you the transmitted and reflected rays in a striking experiment. The best example we have had of ab-

[1] Really many, many sunbeams.

sorbed rays was that of the black velvet, which received j
the same amount of light as the other objects you tried
the same time, and yet the velvet scarcely shone at
Where did the rays go to? Are you surprised that peo
should fancy that the velvet drank them up? Certai
they were not reflected, and yet they disappeared as t
light would from this candle if I put this hood or ext

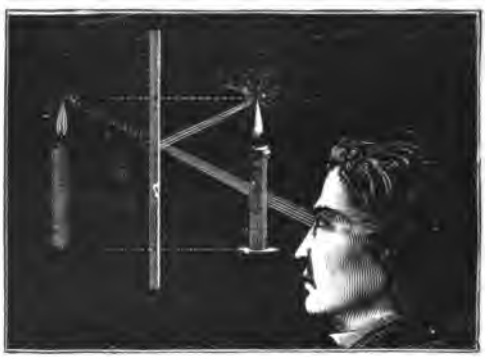


FIG. 37.—THE PANE OF GLASS IS A MIRROR. The rays strike the glass first, and then bend back to your eye, forming an image there, which seems to come from behind the mirror. As I move the candle nearer, the image comes to meet the candle. The image appears to be as far behind the mirror as the candle is in front of it.

guisher on. But we do know a little about these absorbed rays. You, Harold, have a black velvet suit on, while Percy has on a light sailor suit. Come, both of you, and stand in the sunbeams. Percy's suit reflects the light and shines, while yours, Harold, is scarcely lit up by the sunshine at all. But the sunbeams are busy doing *other work* on Harold's suit—they are *making him feel very warm indeed.*

Here is a bottle of water—you see it, don't you?—and you still see it even through this pane of glass, because the

rays are transmitted, or sent through the glass to your eye. You also see this candle I am lighting, because it sends its rays *direct* to your eye. I take away the water-bottle and put the candle in place of it; you now see the candle *by transmitted rays.*

I put the candle in front of the glass, and you (some of you, I am sure) see the candle itself as before, and also its image by reflection. That is, the rays strike the glass first and "bend back" to your eye, forming an image there. In fact the pane of glass is a mirror (Fig. 37). As I move the candle nearer the image comes to meet the candle. Roger, we will have the black blind down, so that all can see. What difference has that made, children? The pane is a great deal better mirror now, Regie thinks. Again, I move the candle further away; the image goes further back—in fact it goes just as far back as the candle moves forward, but you need not bother about that now.

FIG. 38.—The candle seems to be burning in the bottle of water.

I put the bottle behind the pane and you see it by transmitted rays, and now, placing the candle in front, you see its *image* by reflected rays, and by moving the candle as far in front of the mirror as the centre of the bottle is behind it, the candle *appears* to burn in the bottle of water (Fig. 38).

I have shown you that some of the rays from the candle are reflected, making an image which appears to be behind the mirror. I have also shown you that some of the rays from the candle have been transmitted *through* the glass, and enable us to see the bottle. For, remember, it must be

the rays from the candle alone, for we have shut out all other light.

Now I am able to answer a question, which, though Minnie and several others have asked me, I have had to

FIG. 39.—THE KING OF BIRDS.

put off. Minnie says, "How is it that I can't see out into the street when I take a candle in my hand and look through the window at night?" That is exactly similar, except that you are so very near to the candle. The window is a mirror at all times—not a very good one if you stand

right in front of it; but if you stand or sit away on one side, or hold your head sideways, you can see objects reflected very well in it. If you look very "sideways" you will probably see an image of the fire by reflection, and, as in our last experiment, probably something by transmission—say, the street. Then you have, to all appearance, a fire burning in the street. Now as the light outside grows dimmer and evening comes on, your window is better as a mirror but worse to see objects *through*. When you hold the candle to the mirror and put your eye quite close, in vain you wink and blink, but you see nothing outside. You are nearly blinded with the rays reflected from the candle into your eyes. If, however, you hold a screen of some kind, a book, or a board, or a tray, in your right hand or in your left, and put the candle at the other side of it, so, I think you will be able to see something, but you must not expect too much light from a candle.

Home Experiments

17. Repeat the experiment with the candle, bottle of water, and pane of glass.

18. Try to see out of the window, by screening off the candle-rays from the eye.

CHAPTER XI

SPECTRES

I KNOW that you have all tried the candle in the bottle experiment, so that we shall continue our story. We will try another experiment. Hold up your slip of glass straight in front of you, with its long edge resting on the desk. Take a thimble or knife or pencil, or some other object out of your pocket, and place that in front of the glass. Tell me, do you see its image? No, don't move your head; I see you remember the other experiment similar to this. Keep your head quite still this time, and move the glass instead. Turn the right-hand side of the glass a little nearer to you—yet a little nearer. Now do you see the image? "Yes!" Where is it? "As far behind the glass as the object is in front of it." Turn the right-hand side a little more. Now you have the short edge of the glass opposite to your nose. Do you still see the image? Lay down on the desk your slate on your left hand, your drawing-book (open) on your right. Keep the edge of the glass exactly in front of you. Put the object on your slate. Its image is now on the drawing-paper Do you see it? "Yes." Don't you, Ruth? Then shut the right eye. Ah! that has made the image very clear, so clear that you may trace it over with your black-lead

pencil. Now look how I arrange a *Spectrograph* for use at home. First, I lay down a piece of black paper or cloth, then I fix the pane of glass in these large clips, and place the drawing-book or paper on the right and the object on the left of the glass. Now all is complete. The Ghost Illusion is on the same principle. Advantage is taken of the fact that plain glass *both reflects and transmits* rays of light. A large sheet of window-glass (*a*, *b*, *c*, *d*, fig. 41) is reared forward on the platform, say, by being caught in a noose of cord which hangs from a hook in the ceiling.

FIG. 40.—THE SPECTROGRAPH. Fred traces over the spectre of the object (K) which he sees reflected behind the upright pane of glass (A, B, C, D). Observe that the pane is entirely to the right of the boy. Would looking-glass do?

Under the platform, or otherwise hidden from sight of the people, is a man (*e*) with arms extended. A large sheet or tablecloth is thrown over him. He is brilliantly illuminated, generally by the lime-light from a lantern under the stage. The image of the man below is seen upon the platform (at *f*) behind the glass. The assembly see the spectre *through* the glass. The performance is made more interesting if a real man who struggles with the ghost is introduced upon the stage. The spectre is caused to vanish and reappear by shutting off the light from the lantern for a short time.

Now let us try to make the ghost. You all know how to make a Turk with your handkerchief. Take a good look at him while you may. In a moment he will disappear. John, draw up the blackboard (not the easel) against the

FIG. 41.—HOW WE MAKE GHOSTS APPEAR.

end of my table. I shall make a hole near the top of the blind, and then you may push the table up until the sunbeam falls on it, and replace the blackboard. You do not see the Turk, for he is behind the blackboard. My right hand is resting on the table. Directly that I hold this sheet of glass in the right place you will see the Turk's ghost. Yes, it is a real ghost. For see, Albert passes his

hand through it again and again. You will notice that the ghost is leaning. That is the drawback to this plan. If the Turk will kindly lie on his back with his feet to the mirror, I will so incline the pane in my left hand (45°), that his spectre shall *stand up*. But he cannot go through his antics very well, or even appear to walk about in this, the only position which gives an erect image with one mirror.

Here is a better plan. Look at this other picture with me. You see there is a platform or stage, two sheets of glass, and a wooden wall or partition, which comes up above the level of the platform, and screens the lantern and the man who is standing under the stage from the sight of the company who are looking on. First, we will see what is being done on the lower story. There is a man clothed in white standing in front of a mirror. The limelight from the lantern is caused to fall on his garments to make them radiant with light. His image will be seen behind the mirror. It is not shown in the picture. This image is so bright that it forms, as it were, a new object *lying* on the floor, looking up into mirror No. 2, which is on the stage. You see the image of this image at the back of the stage. The spectators see the image by transmission through the last mirror that we spoke of; it is a sheet of plain glass—so is the one below, but with the help of black curtains and the darkness of the room,—the only light coming from the ghost,—the people don't see the glass. Notice that the mirrors are made to lean very much. We have learned that to use plain glass as a mirror we must either look sideways into it or slant the glass. Observe that the mirrors are parallel. The ghost is *brighter* if the *lower* mirror is silvered or even blackened at the back. If *only one* mirror be used, of course it must be *transparent*.

By and by we shall see some coloured ghosts. When

FIG. 42.—PEPPER'S GHOST.

the white light of the sun falls on anything, even though that object be a black "smut" as you call it, it sends back *white* light to our eyes. The "speck" of soot reflects the light and makes itself seen.

When sunbeams fall on this red rose some of them glance back to our eyes. What colour will they be? "White." That is right, because the sunbeams that fall on it are white, as all sunbeams are. But some of the sunbeams go inside the rose and are there shaken up so that the colour-rays are separated. The rose keeps all of these rays except the red, which she sends us back with the message that "The rose is red."

So when the light plays on this green leaf and covers it with sunshine that we may see it, some rays, too, go inside. Then there is such a fluttering within the leaf where the rays are dancing to and fro, to and fro—merrily—busily—only the green ones escape to our eyes to tell us the colour of the leaf. The red, the yellow, the orange, the blue, and the violet rays are caught, and held prisoners by the leaf. "Imprisonment with hard labour" is their fate. The leaf bids them help her to digest the food and make the sap and juices on which the plant feeds. *How*, as I said before, puzzles the cleverest of men.

Suppose some one says to me, "I intend to give an entertainment. I wish you would lend me some little girls." Suppose that I select fourteen of you and your mothers dress each pair in a different colour. My friend then says "I only require seven, I am very sorry for the mistake," and sends one of each colour back. The other seven little girls go into the feast and dance about from place to place till tired, but they cannot get out—except the little girl in green, who comes and tells us that all her companions are held fast. Sometimes no rays come back

to touch those telegraphic cords which we call nerves. What colour is the object in that case? It is "no-colour," you say. What colour is no-colour? "*No-colour*" *is black.* Sometimes *all* the rays come back to tell us, then the object is ——? (white). I hope now you understand that *bodies have no colour of their own* but depend upon the light in which they are *looked at.* For example, this rose is red—why? Because it sends the *red* rays back. Where did it get the red rays? Out of the "all-coloured" light. It could also send red rays back out of red light, but not out of blue light or yellow light, because the red rays are missing in such light. Neither can this green leaf send back green rays, unless in the light we let fall on it the green rays are present.

I see you are looking very wistfully at the little box in my hand. It is some time since I took these matches from a little boy who brought them to school, but boys have long memories. If the owner will raise his hand, I will ask him if he objects to my using them to add to our common stock of knowledge. Yours, Donald, and you will be delighted—thank you,—I hope that we shall all remember the lesson better by the help of your matches. These matches give red light only. All other rays are missing. Before I strike the match tell me what colour the rose will be? Red, you say—why? The leaf? You don't know—will it be green? No, very good! You wont prophesy about the leaf? Things that are white now, such as this pinafore, will be ——? (red). Now I strike the match. What colour is the leaf? Black, etc. etc. etc.

Tell me, now, if I had used pure yellow light instead of red what colour would the rose be?—and the leaf? Let us try. I pour some (methylated) spirits of wine on some salt in this saucer and light it. Everything white or

yellow is made more vivid, all other colours are black. Where is your red frock now, Susan? I question if you have a right to call it a red frock, seeing that it changes its colour so easily. *It is only a red frock in the presence of red rays.* I don't even think I can consider any of you as fair little children any more, you look very ill indeed—quite alarming! I do too—is that what you say? We'll try another experiment.

I shall distribute these inch squares of paper of all colours. This is an experiment for home, but I must show you how to arrange matters. You will find it very simple after the last one. At home you will sit with your back to the window in a good light, and have some black stuff or black paper in front of you. You will easily understand how like this experiment is to the candle image in the bottle. Instead of the bottle I put this large square of blue paper behind the pane (which rests in the bull-dog clip). You all see the blue by rays transmitted by the glass. I must place this yellow square just as far in front of the glass as the blue one is behind it, so that the image of the yellow square shall appear just in the same spot. Some of you, at least, will see a green square at that place. Do you think you can do the same with the slip of glass in front of each of you? (Fig. 43).

Take up the red square and place it right opposite to you as far forward as you can. In the same straight line nearer to you put the yellow square. Hold the slip of glass erect half-way between. Now who can get his glass and papers correctly arranged first? You, James, may tell me what colour you see in the glass. Orange—that is right. Now exchange the yellow square for blue. Who can tell me what colour there is now? Frank says violet—is he right? Now you shall finish that experiment at home

and we will try something else. Open your drawing-book at a clean page and place it in front of you. Put your clean slate on top of that and place the orange square on the slate. Now look steadily at the orange square for a whole minute, then lift away your slate very quickly with your right hand and look down on your drawing-book, and you will see a square of paper of just the same size and in the very same place, but not orange. Try it and tell me if yours is the same colour as mine—mine is a very pale shade of blue (sky blue). You see it, some of you?—yes, you want a little practice. Let us try another square in the same way. Try that pink. The pink leaves a green ghost behind. You all saw that. Now we will try the violet, and I will ask you not to call out, but to put up hands, as soon as you see the image that follows violet, so that those who are not ready shall not be disturbed. Now, Harry? "I don't know whether to call it yellow or green." Well, is it more like yellow or green? "I've lost it now." Yes, it very soon goes; begin again. Can you tell me, Harriet? You say it is yellow turning green; that will do very nicely, or we will call it "greenish yellow." Try the red square. Janet says the colour left behind is green turning blue, so we will call it bluish green. You have a square there that is not exactly either blue or violet; perhaps it is intended for blue—try that. You have soon found that out, Bob. Yes, it leaves a decided yellow. Now try the green square. The green square, you tell me, Rachel, leaves pink behind. Yes, I

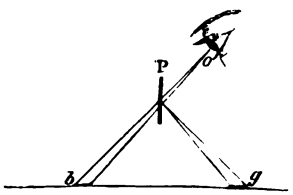


FIG. 43.—COLOUR SPECTROGRAPH. P is a plate of glass held midway between the coloured squares *b* and *g*. The eye at *o* sees at *b* the colour *g* over the colour *b*.

am glad you remember that the pink gave us green. So you see it is as though the pink and green changed places —is it not strange?

Ah, you want to know why it is, and I do not blame you; but I am not at all sure that you will understand me if I tell you, but perhaps you may remember what I say, until you are old enough to think about it.

I have spoken of the nerves as telegraph wires, as it were, that carry messages from all parts to the head-office —the brain—messages about all that is going on—all that we see, hear, and feel. The nerves of hearing reach from the ear to the brain. The nerves of seeing go from the eye to the brain. You will see them like tiny white strings when I give you a lesson on the Eye. It is believed that the red rays have a set of these telegraph wires of their own, the green have their own wires, the violet theirs, and so on for every colour that there is in the spectrum, and that they never send messages on each other's wires — they couldn't if they would. But these nerves are not of wire, but of a very delicate substance that soon gets "tired out" and can't do another stroke of work. Then that particular telegraph office is closed—no more messages are sent until the nerves have had a holiday. Let us see how this applies. You looked at that square of red paper until the office belonging to the red rays had to shut up. Then you looked at the white paper and expected that, as usual, rays of every colour would telegraph at once to the brain —one would telegraph "the paper is violet," another would send "the paper is indigo," another "the paper is blue," another "the paper is green," another "the paper is yellow," another "the paper is orange." The brain would receive all these contradictory messages the same instant, and would be just going to say "the paper is all-coloured," but

would find that one message was missing. Who can tell what that missing message should have said? Lucy says "the paper is red." You are right. So instead of saying the paper is all-coloured or white, the message came ——? (the paper is bluish green).

Do you see how like this experiment is to the one we had the other day when we allowed part of the spectrum to fall on Louisa's pinafore and held the other part back? Do you remember, too, when we allowed all the rays except the red to slide off the card? Louisa's pinafore was ——? Pale blue, Percy says. Yes, how was that? I think it is because this red does not quite match the red band in the spectrum. *Paints are never quite pure* like those coloured lights or that yellow flame that we made with salt. If we had held up a prism in that light we should not have found a single ray on the screen beside the yellow. Try it some day.

But this red square sends back not only red rays but some of its neighbours also—what colour? You can see them quite plainly by the side of the red when you look at the square through this prism as I am doing. The rest of the rays together produced the message—not pale blue, but bluish green.

Again, this violet square left behind a ghost of greenish yellow, instead of the very pale yellow that tinged Louisa's pinafore when we held back violet on the card. You will see that there are some other rays standing up beside the violet when you look at the paper through this prism. And so on with the other painted papers—try them all with the prism. I don't think you will find any of them *quite* pure.

There is another curious thing about these pairs of colours, that is, that they always look well together—better,

in fact, than any other colours. Several of you girls have white pinafores on, but Louisa's pinafore looks best somehow, that is because the black frock makes it look whiter than yours. Your navy blue frock, Jessie, with its gold-coloured sash pleases our eyes. I might mention other little girls and boys too who have just hit on the right pairs of colours. Now that you know the secret, you will be able to suggest to mother what colour will go best with your next new frock, Ida. You will gaze at a piece of the material until those nerves are too tired to send any more messages, and then you will see the colour you wish on the piece of white paper.

Now I believe I have redeemed my promise. I have shown you ghosts of various kinds and colours. "Please, teacher, Ethel wants you to show us 'The Bogie Man.'" What is he like, Ethel? Is he the familiar "Black Bogie" who is said to run away with naughty boys and girls? "Ethel doesn't know, she's never seen him!" Well, if a Black Bogie will do, I have here a little man that I cut out in white paper last night. I will fasten it to the centre of the blackboard with gummed paper. Now I take the blackboard further away, so that you can see the whole figure. Look steadily at it while I count twenty slowly. One, two, three . . . twenty. Black Bogie is on the ceiling! Quick!

Home Experiments

19. Draw me a picture with your spectrograph, taking a penny as an object. First draw the Queen's head side, then turn over and make a separate drawing of Britannia. You may also draw a knife and fork.

20. I am giving each of you squares of coloured paper

to take home ; combine them by holding up a strip of glass, and write down the results.

21. Also write me down what colour goes best with each of these, as well as you can. Then you may have the papers to put on your tops—*e.g.* cover half blue and half yellow, spin the top, and you will see green.

CHAPTER XII

THE BURNING GLASS

I HOPE you have not forgotten your experiment of trying to read through the piece of thick glass. You remember how the lines of print were displaced, and you remember too how much more the rays of light wandered from their regular course in passing through that triangular piece of glass which we called a prism. Perhaps since that lesson some of you may have been able to examine the eye-glasses of a pair of spectacles. If so, you found them to be —— shaped? Yes, lentil-shaped, and you remember we called them ——? (lenses). You remember too that I told you that glasses of other shapes were sometimes called lenses. We will speak of those another time. To-day we will keep to the *real* lens, which is lentil-shaped (Fig. 44). Why do old people put these oval bits of glass before their eyes? Let us see! Freddy, come and look at this book through the lens. You say it hurts your eyes and you see nothing at all. Ah! you are not an old man yet! Put the lens away from your eyes. Bring it at first close to the book and read as usual. Now lift it very slowly upwards. You say the letters grow bigger and bigger still. Are they bigger now? No? They are growing less distinct and fading away. Now you can't see them at all. Now what have

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we found out? That there is one position, found by trial, where the object is large and clear. *The stronger the lens is the shorter is this distance.* This lens which you looked through makes things look about twice as large as they really are, and must be held very nearly an inch from the object. Please remember the distance, for we shall want it again. You remember in examining the sunbeam the

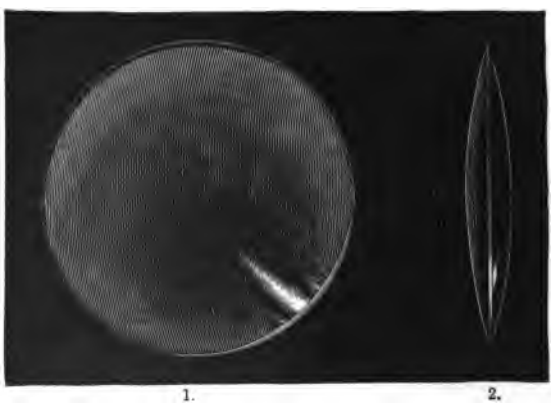


FIG. 44.—LENS OR BURNING GLASS. 1. Face view. 2. Edge view.

first time we found that it was warm and that "heat is always present where light is." This lens "squeezes" up the rays of light which pass through it (Fig. 45). I will show you on the blackboard. It is like a sharpened pencil, is it not? You see the parallel rays are brought to a point like the point of this pencil. Would you like to feel the touch of that point, John? Come here! See, I catch it on a piece of white paper? Do you see the tiny spot? Now hold out your hand—the brilliant speck shines on your skin. Why do you draw your hand away so quickly? It is hot, you say. I should think so indeed! The heat of all the

sun's rays which fall on the lens is brought together in that spot. You will not easily forget, John, your lesson that heat accompanies light. The larger the lens is the more of the sunlight it gathers together and presses into that spot, which is called the "focus" or fireplace of the lens, and is really only the image of the sun formed at that particular spot. With very large lenses metals may be melted. I need not tell you that it is not necessary that the lens be of solid glass. A globe filled with water will act

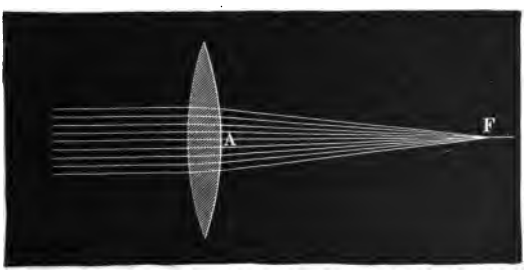


FIG. 45.—The rays of light, after passing through the lens A, are brought to a point at F.

in the very same way, and often becomes a source of danger. A vase standing by the window, holding gold-fish, has been known to set fire to the window curtains. Well, Harry? He wants to know if the fishes were not burned to death. No, Harry, I don't think they were. Can any one tell me why? Dick thinks they might be badly scalded, though. No, the water would scarcely be warmed with the most powerful lens; besides which, the curtains were in the focus, the fishes were not. Nevertheless, if you have any fish at home, you would do well to place them in a north window; the direct sunlight is not so good for them.

Perhaps some of you may have seen a leaf singed by a

burning lens formed by a drop of water, which has drawn strongly together the sun's rays on that particular spot (Fig. 46). I have often seen marks left behind.

Sir John Herschell tells us that at the Cape of Good Hope the heat was so great that he cooked a beefsteak and roasted some eggs by putting them in the sun in a black box with a glass lid. This box was placed inside another similar box with a glass lid. This was not exactly a burning glass. Window glass has the property of allowing the heat of the sunbeams to pass in while preventing heated air from passing out again—a kind of spider and fly arrangement which gardeners turn to account. Even with our little pocket lens I shall be able to show you something. The sun is shining in. I hold my paper an inch from the lens; you see the image of the sun there. I now push through the paper a match and hold its head in that spot. It instantly takes fire in the focus or fireplace (Fig. 47). I know a gentleman who carries a lens in his pocket to light his cigars with. Did I not see one of you boys with a cannon in the playground? Have you it with you now? Can you charge it quickly? Now do you remember the focal length of our little lens? Several hands up! "One inch." Thank you! Now where is the brave boy who will hold this lens one inch from the touch-hole when the cannon has been placed in the sunshine?

FIG. 46.—NATURE'S BURNING GLASSES.

Now as I have told you of the dangers of the burning glass, let me speak of one way at least in which it has been made useful, and which our experiment was intended to show. I don't know if any of you have ever seen a sun-dial; there are some still in country places, but since clocks

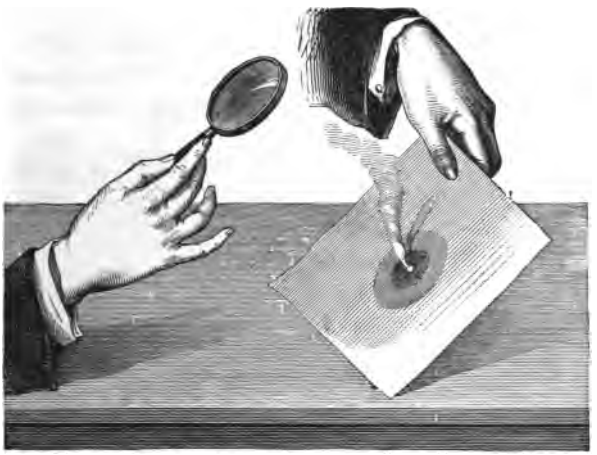


FIG. 47.—"It instantly takes fire in the focus."

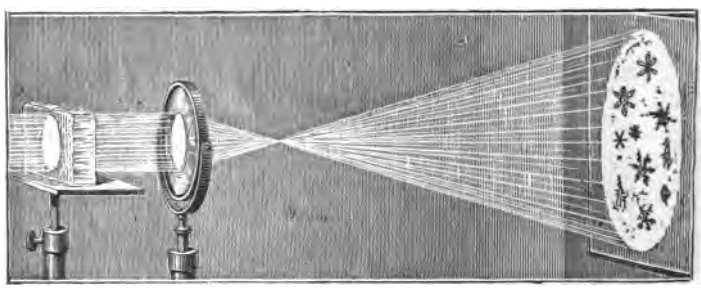
and watches have become so cheap that almost everybody has one, sun-dials have gone out of fashion.

Ah yes, I'm glad that you remember "Isaac's dial," on the walls of Newton's house.

In some sun-dials a cannon and a lens are so arranged that at exactly twelve o'clock noon, when, as you know, the sun shines due south, his rays shall fall upon the lens and be focused just on the touch-hole of the cannon, with what result you may guess (Fig. 64).

When Winter comes I should like you to make a large lens of ice. Any transparent substance will make a lens, but to get fire out of ice is most striking.

Travellers towards the North Pole have been able to kindle a fire in this way, to the great delight of the sailors and natives. I was going to tell you how to make your ice-lens, but I expect you would forget how before Winter came. I heard what you said, Gerty Smith. You told Fanny that I had some ice, for you'd seen it. You will see it again presently. You wonder where I got it this summer time. You say I got it from the fishmonger's, but you will wonder even more when I show you something



2. 3.

FIG. 48.—TAKING DOWN THE ICE-BUILDING. 1. Ice. 2. Lens. 3. Ice-flowers on screen.

that you failed to see, although you don't miss much! To return to our story—the easiest way for you little folks is to get Jack Frost to make a lens for you. "Will he?" Yes, if he is in the humour. Borrow the tin basin that you wash your hands in, in the kitchen, or an old pint basin that your mother doesn't want, for when Jack Frost makes a lens he often breaks the dish—that is a little peculiarity of his. Fill the basin with water and put it outside at night; you will perhaps find a lens in the basin in the morning. If the frost is not severe put less water in. You will have a very powerful lens. If it be fast in the basin pour a little water in the dish and the lens will come out easily.

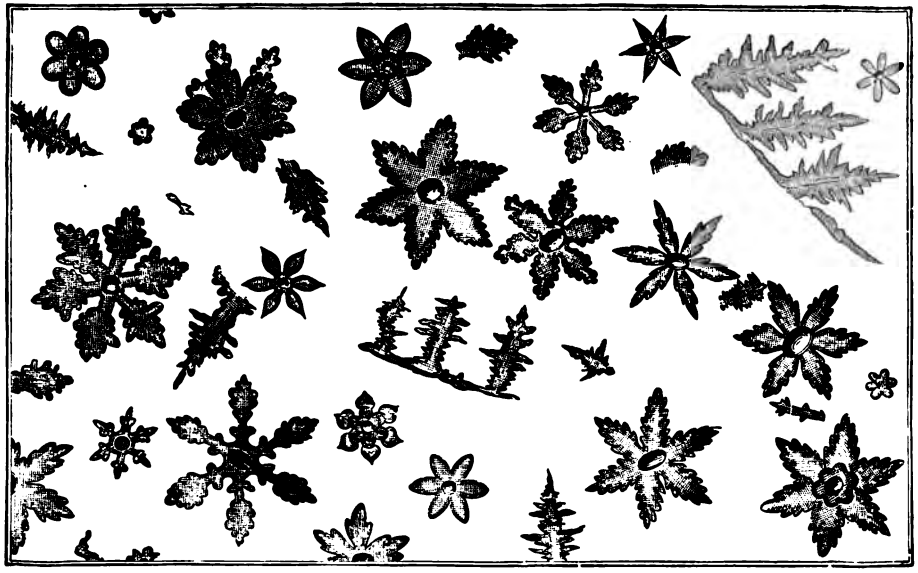


FIG. 49.—ICE FLOWERS (Magnified).

A gentleman once made a burning lens which measured a yard across; this was so powerful that iron plates were melted in a few seconds; tiles and slates became red hot and changed into a kind of glass. All the metals were easily melted: gold ran out in a stream like water. "Wouldn't that lens make water boil?" Johnnie wants to know. That depends. If a clear glass bottle be filled with very pure water, neither the glass nor the water will be more than slightly warmed, even in the focus of the lens; but, strange to say, a piece of wood in the water would be burnt to a cinder, or if you threw a bit of metal, such as a half-penny, in the water and focused the rays on that, you might bring the water to boil.

Now I shall try to show you what ice is made of. You are quite right in saying that it is only water frozen, but you have not learned all Nature's secrets yet. Our magnificent Town Hall is *only stone*, and your house is only brick, and so are many other houses, more handsome, as well as some less pretty. You have watched the builders lay brick upon brick and stone upon stone, and yet if you lifted those bricks and stones off and threw them in a heap you would still have the same quantity of the same material, but not a Town Hall or a dwelling-house. Before the builders are employed, clever men plan out what form the building is to be, and make drawings showing how the materials are to be placed, and the builder looks at this and does as he is told. The bricklayer makes the house, but he does not do the thinking and planning, and that is really the part that makes the difference between houses. Nature too builds according to plan, if it be only a block of ice. We shall slowly take down part of this building to observe how Nature fits the beautiful materials together. We shall not require the burning glass for this experiment.

The parallel beam sent in horizontally through the hole (one and a half inch in diameter) in the blind will be sufficient. In the sunbeam I place this slab of ice two inches square and half an inch thick. An inch beyond the ice I place my lens, which will magnify what is going on inside the slab, and if I place the screen four or five yards away you will all be able to look at it at the same time. Now watch! See that tiny star with its six rays, and there is another! Are they not like flowers? Observe the saw-like edges of the petals. They are almost like fern-leaves. You did not think that Nature fitted such beautiful figures together to make ice. It only looks like common glass, does it? But how different! Now the whole screen is one flower garden!

Home Experiments

22. With your reading glass or the water-bottle as a burning glass, light black tissue paper, brown paper, matches, melt wax, etc. etc., by holding in the focus.

23. Lenses that are hollow in the middle instead of raised up make objects look smaller. See if you can find a tumbler with a hollow underneath; look through that hollow at the things around you.

CHAPTER XIII

THE MAGNIFYING GLASS

THE pocket lens which we used in our last experiments was a simple microscope. So now you know several names for the same thing, viz. magnifying glass, lens, burning

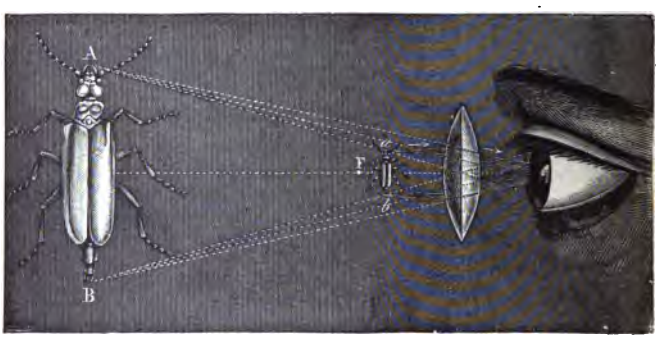


FIG. 50.—MAGNIFYING GLASS (Simple Microscope).

glass, microscope. In the time of Christ it was known that writing appeared larger when seen under a glass globe containing water. I daresay you have often seen objects through the water-bottle. If not, try the experiment yourself next dinner-time.

You remember, in our last lesson, you saw objects magnified by means of my pocket lens, the focus of which

is one inch. In order to use the lens as a simple microscope the object must always be placed between the lens and its focus.

In the picture (Fig. 50) you will see the focus is marked with a white dot and the letter F above. Between it and the lens you will find a little insect marked *a*, *b*; further away from the eye you observe a magnified image of the same object marked A, B. Strange to say, this is not a real image,

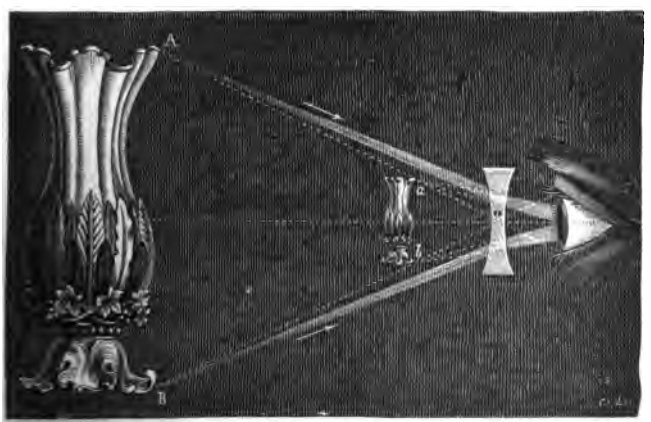


FIG. 51.—DIMINISHING GLASS.

such as we could receive upon a screen held in that place. It is an optical illusion—a ghost, in fact—a something that we fancy we see, but which does not exist at all.

By way of contrast, I must show and explain to you the opposite kind of lens, which you tried to find at the bottom of a tumbler. Many of you made this experiment at home. Objects can generally be found there to illustrate our stories, if eyes are busy on the watch.

In the picture (Fig. 51) you will see that the large vase A, B appears *very small* at *a*, *b*, while at the same time it

seems to be *quite near* to the eye. That is all I shall say about this strange *diminishing glass* to-day, so please dismiss it from your minds and come back to the real lens (double convex), our simple microscope.

Several of you have bought the little bulbs I spoke of, and you have found them particularly good burning glasses. If there is any boy or girl still without a lens let me tell you how to make a capital one. Drop a single drop of water on your slip of glass, turn it over and look through the drop as I am doing. Mary, look at this fly through it.

FIG. 52.—SIMPLE MICROSCOPE (mounted on stand). *a*, Simple lens. *b*, Shelf with hole in centre. *c*, Object on glass slip. *d*, Screw for focusing by raising or lowering shelf. *e*, Mirror which will turn in any direction. *f*, Case.

You will see very many objects with these small lenses — either the pocket lens, the bulb, or the drop. Even if you had a large microscope, you would have to see the object first through a small lens, for with the large microscopes we can only look at the merest speck of a substance at one time.

In the compound microscope more than one lens is used, so that what you really see through it is a magnified image of the image—a sort of magnified "Pepper's Ghost," is it not?

You want to know what kind of objects are suitable. You can hardly go wrong. You should see some objects such as these—a hair, a piece of silk, a spider's web, a cat's

hair, the silky down on fruit, *e.g.* the hairs on a gooseberry, feathers, fish-scales, a butterfly's wing, a bee's sting, a spider's claw, the eye, wing, or foot of a fly—in fact, there are so many things to look at that you will be right in examining any tiny natural object you can get, and here you find a great contrast between Nature's work and man's work, for there is no such thing as slovenliness about Nature's handiwork. Look at one of the finest things made by man side by side with Nature's work. Take the finest needle you can find and put it beside something which looks equally fine, say a little hair of a gooseberry, magnify both, and note the difference.

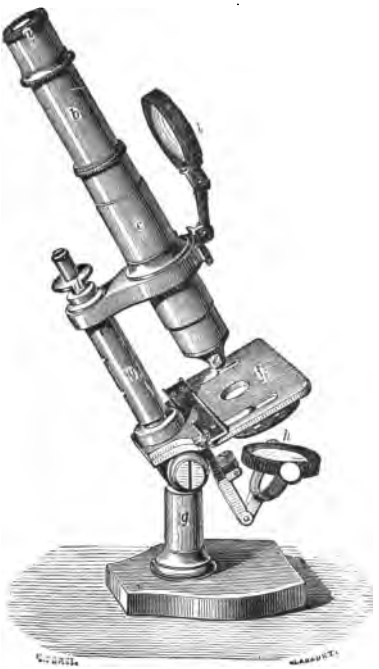


FIG. 53.—COMPOUND MICROSCOPE. *a*, Eye lens. *b*, Body. *c*, Body tube. *d*, Screw for fine adjustment. *e*, Object lens. *f*, Stage for slide. *g*, Jointed stand. *h*, Mirror. *i*, Condenser (movable) for illuminating the object.

The microscope (Figs. 52 and 53) has been the means of finding out more knowledge than any other instrument. Botanists owe to it their most beautiful discoveries of the way in which plants live and breathe. Numbers of small animals that we should have known nothing about have been found. Some of these

produce diseases. You will see how necessary and useful it is to know all about them, so that we can know also how to deal successfully with those diseases. In water which has been standing some time are found extremely minute animal forms, which have been studied by means of the microscope, their beautiful colours remarked, their peculiarities, and even their warlike or peaceful dispositions made known. *Mould* when seen through the microscope looks like tiny mushrooms of the most brilliant colours. You will find your penny bulb useful too (Fig. 71). Get a long cork and fit it into a bottle of water for a stand. Make a hole horizontally near the top of the cork and push the stem of the bulb in. Put a pin through the object you wish to examine and push the pin into the cork below the bulb; you will soon find the right place by trying. Place your penny mirror below and turn it till the object is well lighted up (45°). If the object is very small, such as a hair or a drop of water, push a hair-pin through the cork where the pin was before. This will hold a slip of glass, upon which you can place the object you wish to examine.

See, I will arrange a microscope that you can use in school at recess if you wish. We will call it a Solar or Sun Microscope. You can use the water-bottle if you like (Fig. 54), but here is a gas globe of plain glass which may be bought for sixpence at the gasfitters. You see I have stopped up the hole at the bottom with a large cork. If you have not a cork, soak a piece of bladder and stretch it tightly over as you would cover a pickle bottle. This will not interfere with the rays, as they do not go through that part. We will lay a black card over the top, too, and by and by we will also blacken the portion that the rays

do not pass through, either by using black varnish or pasting black tissue paper over. I make a round hole four and a half inches across in the black blind, and then place the globe opposite the opening for the sunbeams to pass through. This globe is a "water-lens," to collect and squeeze together a great many rays. I place the slide

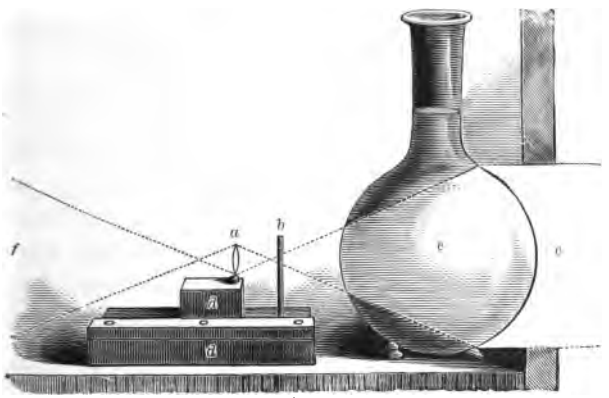


FIG. 54.—SOLAR MICROSCOPE. *a*, Pocket-lens. *b*, Micro-slide. *c*, Hole in shutter or blind. *d*, Blocks of wood (the smaller one slides over the larger for focusing). *e*, Water-bottle. *f*, Screen.

within the focus of the water-lens or *condenser*, which is another name for it. You know how to find the focus.

Look now on the screen! What are those objects that you see moving? Shall I tell you whence they came? A bit of old paste was mixed with water and a drop placed on the slide. They look like eels wriggling about. The intense heat from our water-lens soon kills them.[1]

Now I will put in another slide. I shall dissolve a

[1] A cell containing some saturated solution of alum will remedy this.

bit of this (sal ammoniac) in water and put one drop on the slide. The heat from the water-lens quickly evaporates the water, and the crystals group themselves together, producing pretty pictures like fern-leaves.

The image is always much less bright than the object, especially so when it is very much larger, so that to get a bright image, we must brilliantly illuminate the object. This is effected by our large water-lens, which produces an intensely bright image of the sun at its focus.

You can replace the microscopic slide by a thin, quite flat bottle of good glass. By thin I mean that the parallel faces must be very near together, and the glass not too thick. Into this cell you can put all kinds of water, insects, and weeds. How are you to get them, you say? Bend a piece of wire thus . Join the hooks, wire the ring on to a long handle, and tie a piece of muslin to the ring to hang like a bag. In searching for water insects dredge the pond at its edges and turn out the contents of the net into a basin. When you get home sort out the insects, keeping each kind in a separate bottle. Change the water in your bottles every morning and cast out any dead insects. In an hour's search you may collect a dozen different kinds.

Home Experiments

24. To-day I want you to try to make a lens with a slip of glass (or bit of wood or metal with a hole bored in) and a drop of water, as I showed you just now.

25. (*a*) You may steep some hay or leaves in warm water and let it stand some days.

(*b*) Make some paste and allow it to go sour.

(*c*) You may also make the net I spoke of and collect some

pond insects. For a penny you can buy at the optician's a slide with a little hollow in it and a cover of thin glass. This will answer for the tiny insects contained in pond-water, hay-infusion, etc., to be examined with the solar microscope. The larger ones must be examined with the simple lens or reading-glass, fixed in the cork, with the mirror below.

CHAPTER XIV

FAIRY FOUNTAINS

TO-DAY we shall try to make a fairy fountain, such as you may have seen at the Exhibition. Before doing so, however, I wish to make sure that you all understand what is meant by *total internal reflection*. That is the principle of our fountain. I shall ask each of you, as you pass my table on the way to your seats, to take the glass of water in your hand and, looking up into it, observe the inverted image of the candle (Fig. 55). You are now in a position to appreciate intelligently the fairy fountain. We use either the water-bottle or the gas-globe which we employed for the solar microscope in the last story. The glazier from whom I bought it has cut this hole ($\frac{1}{4}$-in. diameter) on its equator. (When the globe is not required for a fairy fountain the hole may be stopped by a close-fitting cork and turned into the shade, as only those portions of the globe are made use of as a lens which are opposite to the hole in the blind.) I may either fill our globe with water or connect it with the water-tap by means of tubing; in the latter case the experiment will last longer. However, this time I will have by me a large jug of water and pour in gently as required; by and by I shall connect it with a pail of water above by means of this siphon of lead gas-

piping (2 or 3 feet, at 1½d. per foot). You see that I bend the tube, so as to make a long arm and a short one, like the first part of the letter *m*. The short one must dip

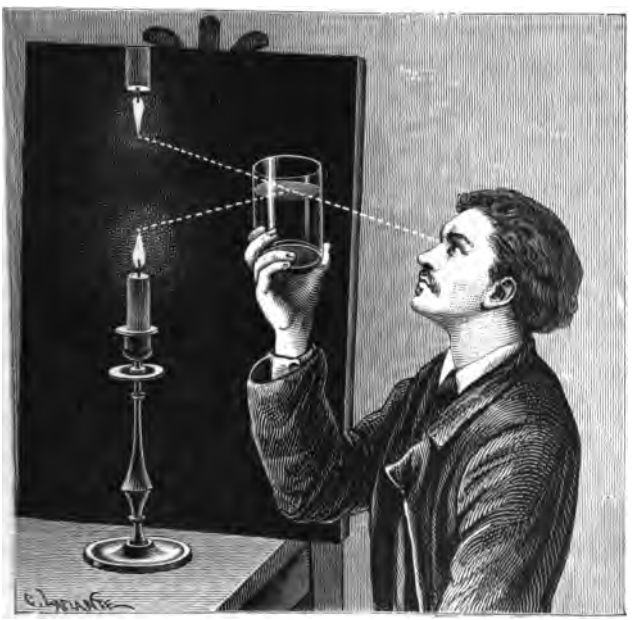


FIG. 55.—TOTAL INTERNAL REFLECTION. The image of the candle is seen on looking in the mirror-like (under) surface of the water.

down to the bottom of the bucket or jug if you wish it to be emptied.

We make a hole in our blind, send a horizontal beam so as to enter the glass opposite to, and shine out at, the hole in the side. Now, having found the right position for the flask, and placed a pail beneath to receive the water as it falls, I fill the flask, and now remove my finger. The water flows out in a graceful curve into the bucket beneath.

It seems as though not water but living fire came forth. Gaze at the strange and magical sight! Ah! What do we see now? I have allowed the globe to run nearly empty, purposely that you should see this. What do you see? What puzzles you? You see the *curve* has gone, and instead you have a horizontal line of light stretching across the room from out of the hole.

Why, then, does the light not shine across the room this way when the water is escaping? You think the light should shine as it does now, and the water stream out in a curve as it always does. In our waterfall the light and the water come out together, the water forming a sort of tube with the light travelling inside. The light is reflected again and again from the inner face of this water-tube, and in its efforts to escape and go along its own straight path, it is jostled first to one side, then to another, then back again. In this way the water carries its prisoner in the police-van down into the pail beneath, and there we see it shining like a mass of molten silver. Free at last! Is it not wonderful! This is a similar experiment to your reflection-tube (Fig. 34). The rays are reflected in the same way. Now, instead of filling our flask again we will dip the short leg of our siphon into the jug or pail above and let the other end touch the top of the globe. To start the flow you must either fill the tube with water and close the ends, so that no bubble of air gets in; or suck the water down the tube. While you watch the fountain this time try to *realise* what I have just told you about the imprisoned sunbeam. Now I rear this slip of red glass behind the flask in the sunlight. See the crimson flood! I touch it; my hand appears crimson too! See the scattered sparks of red fire as they fall in a shower in the pail. I put a green glass behind, and now the stream

turns green. Here is blue glass, which we will try. So we might go on. I should not like to be obliged to do this until you were tired of it! Look now, I hold this goblet in the stream and catch the water here. It over-

FIG. 56.—THE FAIRY FOUNTAIN.

flows with sparkling light. Flashes and sparks of liquid fire leap from it. And now, as all good things must come to an end, let us not forget the story of the imprisoned sunbeam. Here again we must remember the burning of the motes. You will call to mind how motes act as little mirrors. Were it not for the little specks and impurities

deep water would seem like black ink as we gaze down upon it. This water has not been filtered, and it contains these little speck-mirrors, and so we do see *some* light through the tube, although it is imprisoned. Were the water absolutely *pure* we should see a *black* tube, and the light in the bucket would be more brilliant still. Shall we let the prisoner out here, say half-way down the tube? I thrust my hand through the water-tube and break it up, and the imprisoned light comes forth and illuminates it till it seems on fire. Look in the pail now and see the *drops of fire.*

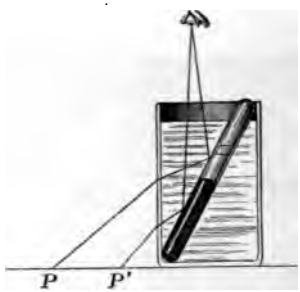


FIG. 57.

This *total internal reflection*, as it is called, may be shown to be brighter than that produced by an ordinary looking-glass with quicksilver at the back. Let us compare the two. We can do so by half-filling a tube with quicksilver, and placing the same in a glass of water. We must lay a piece of white paper on the table. Lean the tube, as shown in the picture (Fig. 57).

See how much brighter is the reflection (P) from the upper (empty) half of the tube than that from the silvered surface (P')!

This is the same kind of reflection as the under surface of the water in the tumbler gave us. You remember, too, we spoke also about the bather seeing not only the objects above him on shore, but also the fishes in the sea. I think now you might be able to understand what I mean by this drawing which I make on the blackboard (Fig.

58). He will see at A (by means of those rays which rise centrally out of the water) the same view of the country round and the sky above him, as if he were in a boat on the surface of the sea, but more compressed; while beyond, on his right hand and on his left (by means of those rays, which do *not* rise out of the water), he will

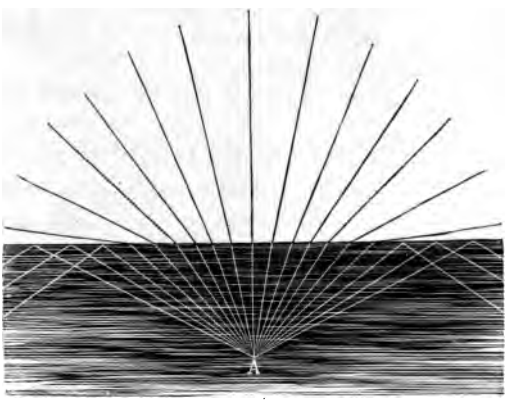


FIG. 58.

see a reflection of the objects, *e.g.* fishes, plants, etc., in the sea.

Home Experiments

26. (*a*) Make a rainbow at home by turning on the tap, and with the thumb directing a *very fine* jet of water towards the horizon. The sun must be shining brilliantly, and low in the sky—or squirt water (outside, of course) against a spoon held as high as possible by some one. Use a penny syringe, to be had at the toy-shops. To see the rainbow colours stand *between* the sun and the fountain. You will also observe them in the dew on grass and on spiders' webs.

deep water would seem like black ink as we gaze down upon it. This water has not been filtered, and it contains these little speck-mirrors, and so we do see *some* light through the tube, although it is imprisoned. Were the water absolutely *pure* we should see a *black* tube, and the light in the bucket would be more brilliant still. Shall we let the prisoner out here, say half-way down the tube? I thrust my hand through the water-tube and break it up, and the imprisoned light comes forth and illuminates it till it seems on fire. Look in the pail now and see the *drops of fire.*

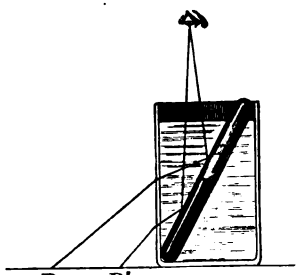


FIG. 57.

This *total internal reflection*, as it is called, may be shown to be brighter than that produced by an ordinary looking-glass with quicksilver at the back. Let us compare the two. We can do so by half-filling a tube with quicksilver, and placing the same in a glass of water. We must lay a piece of white paper on the table. Lean the tube, as shown in the picture (Fig. 57).

See how much brighter is the reflection (P) from the upper (empty) half of the tube than that from the silvered surface (P')!

This is the same kind of reflection as the under surface of the water in the tumbler gave us. You remember, too, we spoke also about the bather seeing not only the objects above him on shore, but also the fishes in the sea. I think now you might be able to understand what I mean by this drawing which I make on the blackboard (Fig.

58). He will see at A (by means of those rays which rise centrally out of the water) the same view of the country round and the sky above him, as if he were in a boat on the surface of the sea, but more compressed; while beyond, on his right hand and on his left (by means of those rays, which do *not* rise out of the water), he will

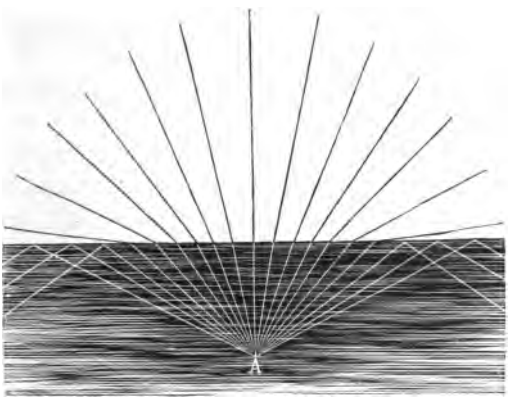


FIG. 58.

see a reflection of the objects, *e.g.* fishes, plants, etc., in the sea.

Home Experiments

26. (*a*) Make a rainbow at home by turning on the tap, and with the thumb directing a *very fine* jet of water towards the horizon. The sun must be shining brilliantly, and low in the sky—or squirt water (outside, of course) against a spoon held as high as possible by some one. Use a penny syringe, to be had at the toy-shops. To see the rainbow colours stand *between* the sun and the fountain. You will also observe them in the dew on grass and on spiders' webs.

but also images of living objects, could be thrown on to the screen. A magic lantern is for *transparent* pictures only, which are painted or photographed on glass slides. The magic lantern is a solar microscope of a rougher kind. I will take this to pieces so that we can examine each part. First there is the tin box, japanned over in this instance. Who can tell me what that corresponds to in our last arrangement? You are right, it is the dark room.

Please understand, that if you went to a shop to buy a solar microscope, you would find the lenses arranged in their

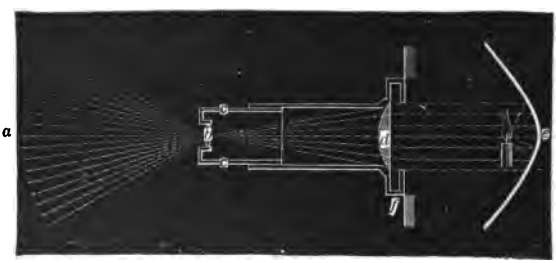


FIG. 60.—MAGIC LANTERN (showing the different parts). *a*, Screen. *b*, Object glass. *c*, Sliding tubes. *d*, Condenser. *e*, Reflector. *f*, Passage for slide.

right positions in a tube something like a telescope; there would be a mirror attached which could be moved into any position by means of a screw (Fig. 59). We employed these separate parts and adjusted them ourselves, which has this advantage, viz. that you see what *duty* each part performs, and how necessary each is to the other parts. Had I bought an expensive instrument and used it, you would have been pleased and surprised, and would doubtless have thought the work done by some *magic*. I am very sorry that lanterns have been called *magic lanterns*, for that gives wrong impression. On the same principle all Nature is agic. Don't you think that a little baby's hands and feet

are magic to him till he finds the way to use them? *We* are magic—every bit of us—and all the world around us. But to return to our lantern, which I said was a rough solar microscope (Fig. 60). By the way, is that true? No! Why? You are right, because we cannot put the sun into our lantern. That is the *great* distinction. What takes the place of the sun in the magic lantern? Ah! I see you are prepared. Yes, this is a little oil lamp. But in the largest lanterns oil is not used. Can you tell me what is generally employed? The lime-light, do you say? Yes, you are right; we will call it that because I can't stop now to explain how it is produced, though I may do so in some other lesson. By cutting a small hole in the bottom of this box we could easily make it fit over the gas burner, which would give us a much better light than most oil lamps. Behind the oil lamp there is a little mirror called a reflector—you know what that is for? All is plain and straightforward so far. No magic yet! What else had we in our solar microscope? A large globe. Right. Where is it? Mary says we shan't require it because we have the light so near the slide. Yes, we want to condense the light on the slide so as to make it as brilliant as possible. See, this large lens called the condenser takes its place. The slide is put near to it in this little passage. Beyond, at some distance in front, is the lens which magnifies the object, and which corresponds to our pocket lens; in this case it is larger and not so round, and is placed further away. Now I think you understand the principle of the magic lantern. Is there anything further that I can explain? Harry wants to know why the front tubes slide into each other. I can easily show you that by lighting the lamp and exhibiting a picture. Now the picture is large, now small. By sliding I can bring the lens nearer or further from the object.

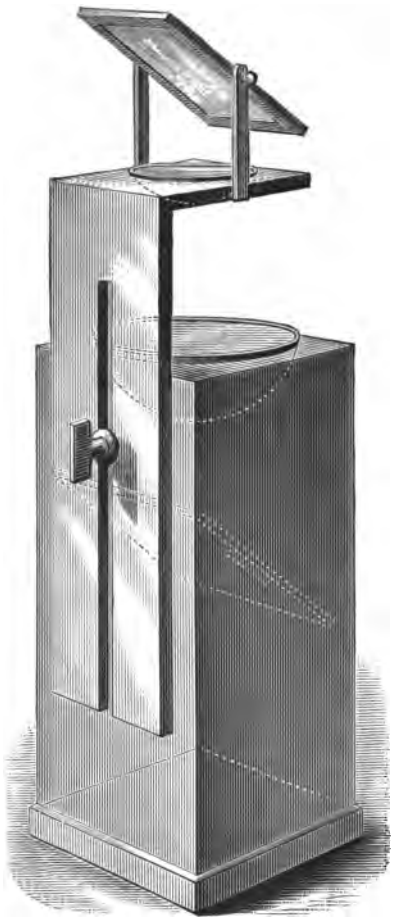


FIG. 61.—SUNSHINE LANTERN. The upper mirror is merely put there to show where a swing looking-glass may be placed, so as to throw images on a screen in any desired part of the room. It is *not recommended*, because fully half the light is lost, and the brightness of the picture suffers in proportion.

The image is so much larger and further away when the slide is near the focus of the lens. Mary wants to know how it is that the image is right side up. That is easily done by turning the slide upside down.

Why do we require a dark room as well as the box? We require a dark room that you may see the image upon the screen. The box is required to enclose the light, and was unnecessary when we admitted a sunbeam through our blind.

Philip wants to know how much a magic lantern costs. He would like to have one, he says. I daresay many of you would like to have lanterns, besides Philip. I have here a little Sunshine Lantern which I made for

1s. 6d. You can easily make such a one for yourself. This, you see, is a small box, a little more than a foot long. You need not be particular that yours is exactly the same length, but it should not be shorter than a foot. Turn it up on end and measure the top, which must not be less than 6½ inches in either direction. This one is 7 inches square. A circle has been cut out of the top and makes it look like a little washstand. Now look what I screw on to it. Two of the walls of a similar box—a short side and a long side; the short side has a circle cut out. This piece, Harry says, looks like a kitchen fender, with one end broken off Of course you will cut out the circle before you take the other sides off, and these you will remove very gently so as not to weaken the joints of those that remain. Choose boxes that are *well fastened* together. Look at this box of round chalk, for example. See how each side has little teeth of wood fitting in together —that kind is best. The grocer has heaps of little boxes, in which cornflour, baking powder, and all kinds of things come—so many that he doesn't know what to do with them, and will be glad to give you one or two.

The box from which you take the two sides must be as long as the first, though it need not stand as high. You see this is from a box just like it—only longer. I lay it down on top of the first with the holes over each other, and find that the top does not quite cover the top of the lower one. You see why? Because the top is attached to the long side which screws on to the back. I take my pencil and draw a line alongside on the top of the lower box, marking as a guide how far it comes. There is really nothing to do except to cut out the circles and make a narrow slot in the long side to slip over this screw. I think you had better ask your father or brother to cut the circles out for you.

But you can mark them out. Begin with the lower box, draw a line from the right-hand top corner or the north-east corner, as the Americans would say, to the south-west corner. Draw another, north-west to south-east. (I forgot, you must go to the corner formed by the end of the black-lead line in this case.) You have made a large X. Drive a tack or nail in the centre where the lines cross. Now take a piece of twine, double it and knot it, as if you were threading a needle for mother—it must be *just* 5 inches long, not more, up to the knot—cut the rest off. Slip this band on the tack and put your pencil point in the other end and carry it round, making a circle. The other circle is made in the same way, but the band may be just 3 inches long up to the knot. The slot, no wider than the screw, reaches from the bottom of the long side, nearly to the top. Buy a thumbscrew just like mine for 4d. They are used for masons' rules. Now, is our lantern complete? I said nothing about the tissue paper, you say. The black tissue paper cost 1d. You need not paste the tissue paper all over. You would never be able to paper the inside of the box if you did, I think. Just paste or gum the edges for about an inch. Harry says he knows there's something else, because that only comes to 5d. Yes, there is. What do you think is missing—it won't be a lamp? No! for ours is a sunshine lantern, you say. What is missing? You are right. We want the lenses, and, as Tom guesses, they are to go in those holes. Here they are! "Sugar basins," you say? No! perhaps not, but like them in one respect, that we may get many sweet things out of them whenever we will.

I don't think you would guess where these came from. They are the tops of glass shades, used for covering ornaments on the mantelpiece. You can buy them cut to

any size. These little basins are just larger than the holes, so that they will not slip through. The smaller measures 3½ inches across and cost 4d.; the larger is 5½ inches across and cost 9d.

Now you have been initiated into the mysteries of the Sunshine Lantern, and if you are very anxious to make one I will cut your circles out for you with my saw. There is one other point yet: we place our hand-mirror—the one we used before, at an angle of 45°, reared up inside the box. You can tell in a minute when you have it rightly fixed, because the sunbeams will go vertically upward.

But to save time in fixing, each time we use the mirror for other purposes I will give you an easy guide. We always have some spare slate-frames in school. Take one of these. Choose a sound corner. Mark off six inches on each side of the joint. Lay your ruler across both marks, thus, completing the triangle. Now draw the slanting line where it touches the wood and saw off. You have now two pieces of frame each 6 inches long joined firmly at a right angle. Fix this inside the lantern so that one leg shall stand straight up against the back wall, and the other lie on the floor of the lantern. Rear your mirror against this, and if necessary put something in front to prevent its sliding down. Now I fill these basins with very clean water, and put a pane of glass over the lower one to keep out the dust. I now place the lantern opposite the hole in the blind, and lay a magic lantern slide on the pane of glass. See the picture on the ceiling. It is not quite clear. We lower the top lens by means of the screw. Is that right? Now we tighten the screw and shall not have to alter it again.

Perhaps you wonder why we have a screw at all in that case. No doubt the lantern once fixed would do for this

particular ceiling, but not for every ceiling. I will now show you a few more of these slides. You see our lantern

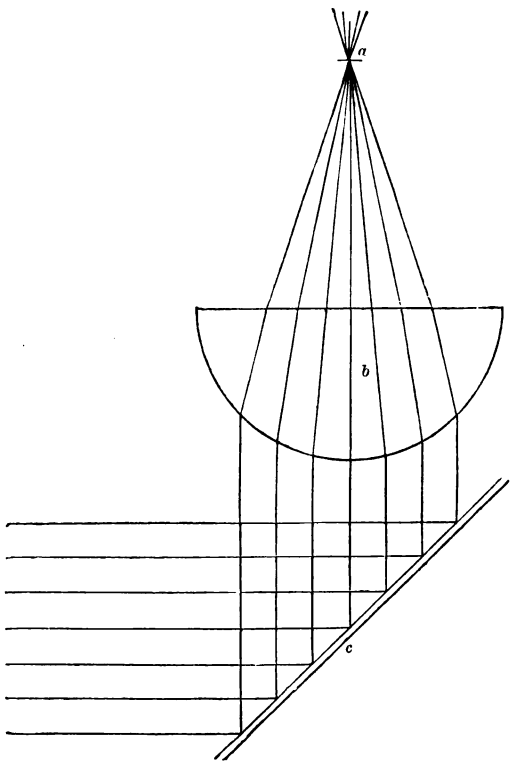


FIG. 62.—*a*, Focus. *b*, Lens. *c*, Mirror.

must be kept very steady or we have ripples on the water. See, I can make circular waves by tilting the lantern. Do you see the image on the ceiling? I shall have much to say to you about these water-waves when you get into a

higher class. See, I can make them come and go with the regularity of clockwork. Count one, two, three, etc.

I drop a cork on the water; see how it pops up and down like a storm-tossed vessel!

You can make lantern slides for yourselves to use in this lantern. For instance—

1. You can make a good drawing on your transparent slate with a hard black-lead. Put a little dye or a little red ink in the water to throw up the picture, and to make a border.

2. Or you may smoke the pane of glass. First warm it, then rub it over with a candle of paraffine-wax, then hold it over a smoky lamp without a shade. Then lay it over the large lens. You can draw all sorts of comical figures on this with a pointer or pencil, and they will be seen growing, as it were, as you proceed.

3. Instead of smoking the glass you may soap the glass well with Castille soap. After rubbing on more soap you can make a new picture—a curious way of rubbing out!

4. Or you may pour milk on the pane of glass and let it dry, then write or draw on it.

5. Another way is to lay the pane of glass over a picture in a book or elsewhere, and trace it with a fine pen. Put a lump of sugar in the ink to make it stick.

6. One of the best ways perhaps for you is to get some paper like the grocer wraps butter, etc., in, and trace in ink upon it—even tissue paper will do, though it is not so easy to work with. Afterwards, to make it transparent, put it on the pane of glass and drop oil or weak gum on it.

7. Perhaps the best way, though not the cheapest, is to write lightly with a needle or a bonnet-pin on thin gelatine, and afterwards, when finished, you should rub a little black-lead into the lines. The rest of the gelatine must be

spotlessly clean. This is useful for the best kind of work when you have time to take pains. The other slides you can make while you are exhibiting them. You can fasten the gelatine down to the book or drawing-board on which you are working. But I have not told you all—could not tell you all—the wonderful things you may do with this lantern. Perhaps you can suggest other ways. Nellie says she thinks it could be used as a burning glass. Yes, we can either use one or both lenses—the focus is easily found. Light some touch-paper, Duncan. Now, you see the meeting of the rays above the water—that is the spot (*a* Fig. 62). This sealing-wax runs like water, and now lights up.

Have you ever considered how feeble all Lantern Entertainments are compared with the views that Nature shows us continually? With King Sol as operator, lighting up by his presence that dome-like screen of finest gauze which Mother Earth so generously provides, *Nature has no rival.* She has so many slides, indeed, that never by any oversight does she show us the same scene twice. I do not now refer to the *special* slides, such as the Rainbow and others of which I shall speak later on, but to those which she shows us Careless Folk every moment when we have the common courtesy to look.

"It is strange how little in general people know about the sky. It is the part of creation in which Nature has done more for the sake of pleasing man, more for the sole and evident purpose of talking to him and teaching him, than in any other of her works; and it is just the part in which we least attend to her. . . . Every essential purpose of the sky might, so far as we know, be answered, if once in three days, or thereabouts, a great ugly black rain-cloud were brought over the blue, and everything well watered, and so all left blue again till next time, with perhaps a film of morning and evening mist for dew. And instead of this,

there is not a moment of any day of our lives when Nature is not producing scene after scene, picture after picture, glory after glory. . . . The noblest scenes of the earth can be seen and known but by few; *but the sky is for all.* Bright as it is, it is not 'too bright nor good for human nature's daily food.' Sometimes gentle, sometimes capricious, sometimes awful; never the same for two moments together; almost human in its passions, almost spiritual in its tenderness, almost divine in its infinity. And yet we never attend to it; we never make it a subject of thought. . . . One says it has been wet, another it has been windy, and another it has been warm. Who among the whole chattering crowd can tell me of the forms and precipices of the chain of tall white mountains that gilded the horizon at noon yesterday? Who saw the narrow sunbeam that came out of the south, and smote upon their summits, until they melted and mouldered away in a dust of blue rain? Who saw the dance of the dead clouds when the sunlight left them last night, and the west wind blew them before it like withered leaves?" (Ruskin, *Modern Painters*).

Home Experiment

27. (*a*) You are going to try to make a lantern slide. I shall give each of you two pieces of tracing paper (like that the grocers use). Fix it exactly on that beautiful picture in your reading-book, page , with these four very tiny tacks, and trace very *slowly* and carefully in ink.

Some of you boys have sheets of transfers. If you meet with any very pretty design that you would like to make a slide of, show it to me, and if suitable I will give you a piece of glass.

(*b*) Lay *good* carbon-paper over glass, so, and above that place a scrap picture. Trace over it with a *soft* black-lead pencil. Here is some carbon-paper. This is one of the easiest and best ways, but it spoils the original picture.

CHAPTER XVI

KING SOL—PART I

I WONDER what time you little folks get up in the morning. Perhaps not very much before school-time. The sun is up before you, filling the heavens with the rosy light of dawn, bringing glad messages to the still sleeping flowers. For the flowers are the "Children of the Sun"; the sun makes these as *actually* as he makes the clouds. The sun smiles on them, and they wake up and open their eyes when they feel his bright warm beams shed around them.

You have watched the flowers close up at night, and in the morning spread out their tiny rays again. You all have noticed the daisy—"day's-eye" it is called, for it spreads out its flowers to the first sunbeam and closes them up as the sun goes down; and I daresay you have observed other flowers besides. Do you know the sun-flower? It is like a very large golden daisy, and always turns its face to the sun (at least this is true of it in other countries, though not in England). Heliotrope, also, means "she who turns to the sun."

Though I said flowers were children of the sun, I might have said that all animal life, as well as vegetable, is dependent on him for vigour and energy, *for the power of doing work.* I should not be wrong in saying that,

whether the power was first obtained from a waterfall,

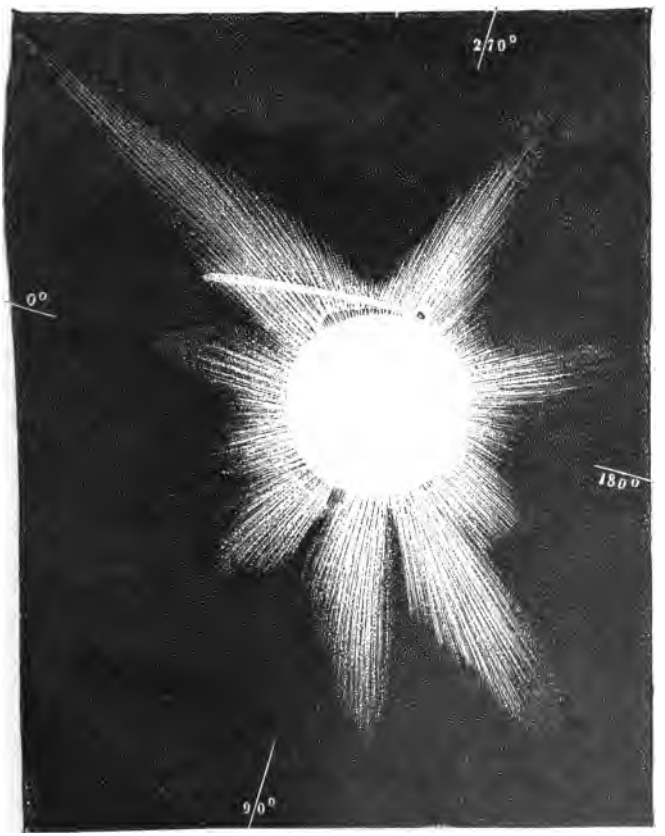


FIG. 63.—KING SOL (see p. 447).

from steam, or from electricity, it could be traced back to the sunbeams.[1]

[1] "There is one tap-root from whence they all spring. This is the ancient maxim that 'out of nothing, nothing comes'; that neither

Whenever work is done, it is by the *un*doing of some work that has been done before. You have noticed your father wind up the clock, and then have watched the big weight come gradually and slowly down again, and when it could not fall any lower the clock *stopped*. Or he wound up his own watch by tightening a spring, which gradually unwound again, as you yourselves sometimes do when tired of swinging backwards and forwards—you go round and round and twist the rope as I am doing with this suspended ball; then you stop and allow the coil to untwist and carry you round with it. When you see the water of the river come swiftly down a bank and turn a water-wheel it looks as if there were no winding-up done, but ever and continual running down. But let us think for a moment. The water rushes away to the sea, and the sunbeams carry it up on high again; as cloud and rain it comes trickling down the hill-side into the stream again. Is not this similar to the winding-up of the clock?

If you would get up very early some morning, I am sure you would not regret it, for there out of the window you would see what we call "sunrise." Does the sun rise and set? No! you are quite right; but these old-fashioned

in the organic world nor in the inorganic is power produced without the expenditure of other power; that neither in the plant nor in the animal is there a creation of force or motion. Trees grow, and so do men and horses, and here we have new power incessantly introduced upon the earth; but its source, as I have already stated, is the sun. For he it is who separates the carbon from the oxygen of the carbonic acid, and thus enables them to re-combine. Whether they re-combine in the furnace of the steam-engine or in the animal body, the origin of the power they produce is the same. In this sense we are all 'souls of fire and children of the sun.' But, as remarked by Helmholtz, we must be content to share our celestial pedigree with the meanest living things. The frog and the toad, and those terrible creatures, the monkey and the gorilla, draw their power from the same source as man."—TYNDALL.

ways of thinking have such a hold upon us, and some people fancy that it is more poetical to say that the sun gets up and goes to rest. I think that the truth would be much more beautiful.

I was about to try to describe sunrise to you as well as I could. I think you had better see it for yourselves. I could not easily explain the way in which Nature paints the clouds. Shakespeare says—

> "Lo! here the gentle lark, weary of rest,
> From his moist cabinet mounts up on high,
> And wakes the Morning, from whose silver breast
> The Sun ariseth in his majesty;
> Who doth the world so gloriously behold,
> That cedar tops and hills seem burnished gold."

Some of you, I am sure, although I will not set it as a lesson, will wish to see the beauteous sight for yourselves, and will rise early to-morrow morning and tell us all about it afterwards. I will recall to your mind something that most of you have seen. You woke up one morning and found the room "pitch-dark" as you call it, but somehow you were restless—perhaps ill, and you could not go to sleep again. Gradually the light came stealing in at the window, till you could just dimly make out the shapes of the furniture in the room. Then you saw more plainly the white counterpane and the furniture near to the window, and all the rest seemed hazy and dim. After that you noticed the wall-paper near growing more distinct, and you saw the knob of the looking-glass and the rails of the bedstead, then the drawer-handles, and by and by everything in the room put on its true shape and colour, and you found yourself wide awake in the broad daylight.

In the evening the same thing occurs in reverse order. Gradually the objects begin to fade out of sight, yet we are not inclined to go to bed. We do not care to sit up in the dark. What are we to do? What is it that we miss?

A very poor substitute is all our artificial light, and what is stranger is that it is only sunshine—very faint sunshine that has been "saved up," so to speak—which we

FIG. 64.—KING SOL'S ALARUM CLOCK.

are able to employ, whether in coal, gas, candle, or lamp. I can't make you understand now how this is, except just to remind you of those sun's rays that I told you were held prisoners and made to work by the plant, and that coals are the remains of plants—yea, vast forests that grew and became pressed together, and buried millions of ages ago. All heat and all light come *originally* from the sun.

You remember when speaking of colour I explained to you how, when the sun shines on a green leaf, only the green

rays came back to our eyes with the message. The red, orange, yellow, blue, and violet rays are seized by the leaf, and made to do work in the interior—the work in this case being to prepare the food, to make juices on which the plant feeds. Now this is the work which is *being un*done as the candle, oil, gas, or fire burns before you at the present moment. The substance of the plant is going back to join its old companions, from which the sunbeams separated it ages ago, that it might become food for the plant, and afterwards the substance of the plant itself.

How do you think these old friends meet again? Do they travel sedately, by a long route, in old-fashioned style, or do they go express? No! Express were far too slow! They rush at each other with all their might the moment that they are free! And so violently do they clash against each other, that they burst into flame in the ardour of their embrace.

Let us imagine ourselves out of doors, gazing wonderingly at the Sun, as so many millions of people have done before us. The Sun is so powerful that unless the day be cloudy we should not look straight up into his face, or we may be blinded. We must look through a piece of smoked glass, or your pin-hole camera, the one I gave you at our first meeting. How near the sun looks. He is only just across the way. Don't you think you could soon mount up to him in a balloon? How far away do you suppose he is? Shall we look in the railway guide? I am afraid the railway guide would not tell us. We should have to ask some very clever man who had thought a great deal about the subject. Perhaps he could tell us. Then we might say to him, How do you know? How did you find out? Have you been there? The right man to ask would be an *Astronomer*. We must find an astronomer who likes

little folks. We will ask Sir Robert Ball, the Astronomer-Royal—perhaps we might coax him to tell us, for we are very anxious to know. He says, "It has been found that the sun is about ninety-three millions of miles from the earth; but sometimes it is a little farther and sometimes it is a little nearer.

Let us first try to count 93,000,000. The easiest way will be to get the clock to do this for us; and here is a sum that I would suggest for you to work out. How many times will the clock have to tick before it has made as many ticks as there are miles between the earth and the sun? Every minute the clock makes 60 ticks, and in 24 hours the total number will reach 86,400. By dividing this into 93,000,000, you will find that over 1076 days, or nearly three years, will be required for the clock to perform the task."

Did you ever travel in an express train? A mile in a minute is very quick for an express train, but imagine the same train never stopping an instant for years. To have reached the sun to-day you would have had to start 171 years ago. If your mother has ever told you anything about her father, I daresay you will remember that she called him your grandfather; his father would be called your great-grandfather, and his father again would be your great-great-grandfather. We have imagined that you started when your great-great-grandfather was a boy, and took your seat in this wonderful train, and reached the sun to-day. Think of it! A train going at ordinary speed without once stopping would take nearly 350 years to reach the sun. It would take the same train nine years to go round the sun, though it would need only a little more than a month to go round our earth.

Let us look again at the sun. There he is, just on the

FIG. 65.—NATURE'S MAGIC LANTERN. Ghost scenes: *The Spectre of the Brocken.* Very occasionally King Sol projects a ghost illusion; but when he can be persuaded to do so, it is a spectacle of most terrific proportions. The traveller Hane relates that he had been up the Brocken (one of the loftiest of the Hartz Mountains in Hanover) thirty times before he witnessed the sight. At 4.15 A.M

line where the earth seems to meet the sky. Let us look all round us at this line where sky and earth seem to touch. Imagine for a moment that we had not only one sun, but many, side by side ranged round this line. How many suns the size of ours would fill up the circle? It would take 700! The sun is "up," as we call it, for more than eight minutes before we see him, and those rays we were experimenting with, and those shining upon us now, took eight and a half minutes to travel here from the sun! What a journey! Ninety-three millions of miles! Is it not fortunate that the sunbeams can come to us, since it is impossible for us to think of visiting the sun.

I daresay some of you will have seen a large balloon sent up, or if not, you boys, all of you, have kites, and you will bear me out in saying that, however large you make your kites, they seem to grow smaller and smaller as they go up, until when they are at no very great height (which you easily can tell by the length of string given out) they become mere tiny specks, and then even the speck vanishes, and yet you know your kite is still soaring aloft, for you are holding it by the string. From this I want you to reason out with regard to the sun — what an immense, enormous, unthinkable size must the sun be to be *visible at all* ninety-three millions of miles away.

To illustrate how the giant Sun *pulls* our earth, we shall

he turned back and walked towards the inn to the south-west, when he observed a human figure of *monstrous size* on the thick mist a very great distance away. He raised his hand to his hat, for the wind was strong; the colossal figure did the same. He stooped to pick up his hat; the spectre faithfully imitated the action, and then the figure disappeared. Presently the innkeeper joined him. Then they beheld two huge figures, which imitated everything that they did. By and by a third figure appeared, which must have been a *double* shadow of one of them. But it is not necessary to go to the Brocken to see the spectre. The same phenomenon has been witnessed on the Wiltshire hills and in Yorkshire. Sometimes the spectre's head is surrounded by a halo of rainbow-colours, visible only to the original of the spectre, not to his companion. Professor Tyndall was so determined to see the Brocken Spectre that he made special terms with King Sol—in fact, provided his own cloud-screen.

not go to the kite for an example, but rather to something with which you boys are quite as familiar. You all know how to fasten a stone in a sling and whirl it round. You are very fond of whirling round fireballs of steel shavings, on Gunpowder Plot. Consider yourself the sun and your little ball the earth. Ah! somebody says, but what is the string? The sun pulls the earth without a string of any kind; that is more wonderful still, is it not?

Home Experiments

28. To-night, after the sun has set, go into the fields and gather me some sleeping flowers—bring only those that are closed up for the night, and if you are too early you must go again or wait. Some of you, I know, will watch to see the sun rise some day this week, so that you can tell us all about it.

29. Look at the sun through smoked glass, also through a pin-hole. If your little pill-box camera is pricked all over take the bottom out entirely, and I will give you the lid to put on instead. In this make just one hole—in the middle; we shall want to use it for many purposes yet.

CHAPTER XVII

KING SOL—PART II

WE have been considering how far the sun is from us, and how he pulls the earth, and how impossible it would be for any of us to pay a visit to the sun. Some one has told us that if a baby had an arm long enough to reach the sun, that baby would die of old age long before it could feel the smart of the burn. Suppose again —it is all supposition, for have we not said that it is impossible?—suppose that by some chance a man got on to the surface of the sun (he would be burnt up long before reaching the sun, you say: he shall be proof against that), on arriving there he could not stand up straight. Why? you ask. Suppose that twenty-six men jumped on to your father's shoulders he would be squeezed as flat as a pancake by the weight, unless somebody propped him up against a wall. If he once laid down to rest, he certainly could not get up again.

I suppose any of you could fetch a two-pound loaf from the baker's without complaining of feeling tired. Suppose that you were living on the sun, you would not be able to lift a loaf of the same size off the counter. Guess how much it would weigh? About fifty-four pounds—almost half a hundredweight! I don't think you would often go to the

baker's though, for you would weigh half-a-ton yourself, and you would find that rather a heavy weight to lift up at each step of the journey. I don't know either how you could amuse yourselves. To push your hoop along would be like trying to make a wall move on. Your ball would be so heavy to play with, it would weigh almost two

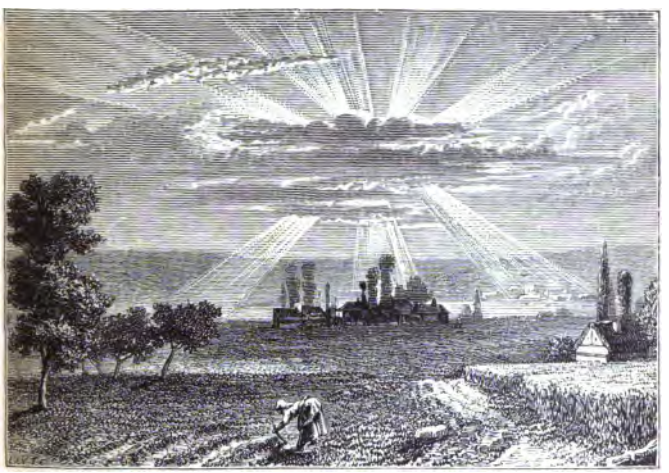


FIG. 66.—NEAR SUNSET. The sun being overclouded, we see more distinctly the fairy sunbeams *moving in straight lines.*

pounds, and would hurt you badly if it came down on your head or even on your toes. You'd play shuttlecock, you say. Ah! no, you would very soon tire of playing shuttlecock on the sun. You would not strike it many times, for it would weigh almost three-quarters of a pound!

We often think of the earth as like an orange, though this is not quite the true shape; it is much rounder than an orange. Suppose I gave you a very small orange and a very large orange, and asked you to tell me how

much larger the one was than the other, you would find it difficult. A good way to compare them would be to cut each in half, and then put the flat side of the small one against the flat side of the large one. Suppose we adopt this plan with the earth and the sun. We should require 110 such earths as ours to cross the face of the sun, and then these earths would look like a string of tiny beads stretched across his great face. But how many earths like ours could you put inside the sun, if it were hollow like a monster football? It would hold more than a million and a quarter (1,331,000) globes the size of our earth. Would it hold the planets then? Yes, all the planets, and room to spare! It would hold the planets, though there were 500 times as many as there are. But even these comparisons do not help us much to picture in our minds the immensity of the sun compared with the earth. We must have it on a still smaller scale. We must look at them through one of those lenses which make everything look tiny. Perhaps you have a globe in school, two feet in diameter; if not, you could make a paper balloon that size. I will draw a circle two feet in diameter on the blackboard. This shall stand for the sun. What shall we represent the earth by? Now, think! I will draw a line across through the middle how long is that line? (24 inches). How many earths could we place side by side on that 24-inch line? You all remember that, I see! Right. And each must be ——? Ah, that is too hard! Four and a half earths will take up nearly an inch. Then one earth will be a little less than a quarter inch. Now try to think what object would represent the earth. A marble is much too large. (The children guessed.) A pea would be about the ize we want.

Let us look again at the sun. What do you think he is? "A big fire up in the sky." Many people believe him to be a vast glowing fiery globe, white hot. Look for a moment at the fire in the stove. The cinders are some of them half black and half red, some are dull red; but see, I will clear a way into the very heart of the fire, and there it is brilliant as well as hot—white hot! so that one can scarcely look at it. But the sun is not like this fire, or any fire that we know of, even if the size were the same. Such a fire would have burned itself out ages ago!

You have learned in your geography class the diameter of the earth, that is, the distance *through* the globe, say from England through the centre to New Zealand opposite us. How far is that? "Eight thousand miles." Yes, if only we could make a tunnel straight through the middle of the earth, as I push this knitting-needle through this orange, what travelling we should spare, though you might like it no better than a sea-voyage after all. Well, the measure through the sun is not eight thousand, but eight *hundred* thousand and more.

Here is a half-penny ball which belongs to one of you. It measures one inch through. Now tell me how large a ball we shall need for the sun, if this inch-ball stand for the earth. No, no, much larger than you are guessing. It would have to be higher than any of your fathers, for I think none of you has a father more than six feet high. Our ball must be half as high again as father. Father with you standing on his shoulder would not be too high! I will measure nine feet on the floor, from this wall towards the opposite one, and then nine feet in the other direction, so as to make a square for the ball to stand on. Now the ball would take up all this room, and stand as high as a giant man, half as high again as any you have seen. I will also mark the height upon the

wall. Now you can imagine glass sides and top to the box covering the space marked out, and having done so, you

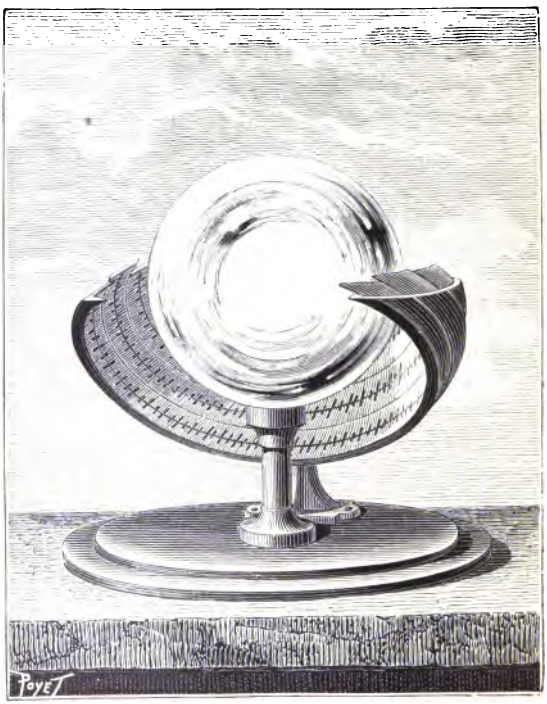


FIG. 67.—ONE OF KING SOL'S ACCOUNT-BOOKS. *We* write by smearing carbon on paper. King Sol, with a pencil of light, carbonises (chars) *the paper itself.* SUNSHINE RECORDER.—Burning glass with concave screen of millboard placed in its focus. When the sun shines a mark is burnt in the millboard. When the sun is overclouded there is no mark. As the sun moves in the sky his image moves also, and thus we have a series of marks; or, where the sun shines continuously, a charred line. (The long and short lines on the screen indicate the divisions of time.)

can easily fancy a large ball that just fits in that box, so that the lid will close. That is the size of our sun-ball

which corresponds with this little earth-ball. If you will walk down the road, moderately fast, carrying the half-penny ball in your hand, and stand still at the end of about four minutes, your earth-ball will be somewhere very near its correct (relative) distance[1] from such a sun. You shall go down to John Robinson's home after school and look towards this place, with the ball in your hand.

The sun is an immense Star. I see some of you evidently think that I have made a mistake. Stars shine at night, your faces plainly say. You remind me of the Irishman who said, "Sure, the moon's more sense than the sun, for she shines at night when it's dark, but the Sun, silly old thing, shines in the broad daylight!" I thought, rightly, you would be quite able to appreciate that joke without any interpretation, still you may not know that the stars are all shining in the sky now just as they are at night. You can't see them? No, you cannot while the sun is shining brightly, any more than you can see the light of a taper in a well-lit room. Do not imagine that the other stars are very small. They are all *suns*, though the nearest of them is at such an immense distance from us—hundreds of thousands of times farther away than our sun.

I don't know if you have ever stood at the door looking out for mother or father coming home, or watched them go away; if you have you will have noticed that you can see the people near to you quite distinctly —they are of the right size—and you can tell their features quite plainly, the colour of their eyes and hair, and the shapes of their noses. Directly they go a bit further off you can't see them so plainly, and if you have ever stood

[1] $\frac{1}{5\frac{1}{2}}$ mile.

wall. Now you can imagine glass sides and top to the box covering the space marked out, and having done so, you

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nile.

at the door and watched them go down the road, you have seen them grow less and less, as your kite did, and when they got a certain distance they had dwindled entirely out of sight, although you were *sure* they were somewhere there.

Again, if you watched for your mother coming home, you said quite positively about the people near you "That's not mother," but when you looked as far as your eye could see, every one seemed the same—an almost invisible speck—and you said, "I see something, but I can't tell you what it is yet; it may be a man, or a house, or a cow, or a church-steeple, but I shall watch if it comes this way." By and by it grew bigger and bigger, as it were (though you know people don't grow up in ten minutes or a quarter of an hour), bigger and bigger still, until you were sure it was not a horse, and had decided it was a man or woman. Then you puzzled and watched to see which, and first said one, then the other. At last it was a woman, you were sure, and she was growing rapidly larger and plainer to be seen, and by and by you recognised that she had a bonnet and shawl on, and was carrying a parcel. But she had to come very much nearer before you could see her features, and then you ran out, sure that it was *mother* and no one else. Isn't it very strange!

Here is a penny—no, I will take a half-crown, because I daresay you may have observed, that you can see a bright object best. I shall not go into the dark, but on the contrary take this coin nearer to the light—keep your eye on it. It grows smaller—smaller—smaller—smaller—don't lose sight of it—it is much smaller now—very much smaller—you must stop me before it goes right out!—smaller still—how does it look now? As large as ——? "Sixpence." Now I go slowly—tell me when it grows down to a threepenny bit—now I shall not go much farther for fear you lose

sight of it altogether, and I am becoming alarmed, too, that my money is vanishing so rapidly! I will put it here in the window, where the light will shine on it; and I will leave it here a while, so that you may remember this little experiment.

Home Experiments

30. Go down the road to the place where I told you, just by where —— lives; take with you a ball of wool, just the same size as our halfpenny ball (1 inch diameter), and holding it up look at the school—at that box particularly, if you can, in which we have imagined our model sun to be.

31. Do you know that all the lamp-posts in our town (with few exceptions) are exactly alike in size and make? Notice them, please, and when it is dark try how many of them you can see *distinctly* from where you stand. I think you will find that you very soon lose sight of the post altogether. You see the lamp part for a longer time, and by and by you can't tell anything but the light. The lamps too seem to draw closer together, and each little light is smaller than the last till by and by it becomes a tiny star, smaller and smaller, though very bright, till it vanishes out of sight, and yet the last lamp that you can see is just exactly like the one beside you. Find all this out, and something new to tell me, that I have not noticed.

CHAPTER XVIII

KING SOL—PART III

WE have brought many images of the sun into school during these "talks"—in fact the room is filled with such images. I will show you how, at the present moment, we may have *one* larger, brighter image to look at as the object of our thoughts (Fig. 68). Lower the blind, Donald. The Sun is like a great father to our earth, and the worlds that move round him. As your string pulled the stone, so the giant Sun draws his family continually around him. I mean that he is *always* doing this, though there are some days when he hides his face behind the clouds—yet he is *there* every day and never leaves his children for a moment. Perhaps some of you may have thought that he was off on a holiday, occasionally, when you did not see him for a whole day—perhaps, too, you thought that we ourselves, together with the rest of his family, would never miss him for a long time, if he should go. I can assure you, that, in less than three days' time, there would not be a plant or animal alive on the face of the globe, except, perhaps, some deep-sea fishes. In two days, every cloud from the sky would fall in floods of rain or piles of snow: all Life would be utterly impossible. Such a terrible frost would set in, as the tops of our highest mountains never felt. This we are quite sure of, for we

know that it is the dampness of the air which keeps the heat of the sunbeams amongst us when we see him no longer, and if once the mists and clouds were brought down, and the air remained thoroughly dry, no animal or

FIG. 68.—KING SOL'S LATEST PHOTOGRAPH (taken in school).

vegetable could endure the frost for an hour, any more than it could live for an hour in boiling water. Ah, these wonderful clouds that keep us from being frozen to death, while at the same time they also keep us from being scorched up, as we should certainly be if the sun's fierce rays fell straight down upon us. What is this pretty cloud

veil between us and about us?—for we don't live under the clouds but *in* the clouds.[1] Tiny, tiny, drops of water which the sunbeams draw up into the air round about us, so fine and small are they that we cannot see them. Last night I was crossing the railway foot-bridge just as an engine passed beneath, so that I watched a cloud form; it wrapped me round until I could see nothing but the white mist, and I could quite fancy how our moist atmosphere wraps Mother Earth round like a blanket, and keeps her warm—I might have said like a very great many blankets, pressing close to her through the night the warmth of those sunbeams which have shone upon her during the day. I shall have something more to say about this in our story of the Moon.

Ah, I see I must break off my story, for if I can read the thoughts of little folks at all, your faces plainly say, "I mean to have a good look at the long tube before I go home; I want to see how it's made." "Yes, that's just exactly what I was thinking, teacher." Who can tell me the name of this instrument? "A spy-glass, teacher. I have one at home; mother bought it at Blackpool. I used to watch the boats come in; the people seemed quite near." Yes, the *Telescope* seems to bring distant objects quite close to us. Here is a picture of a portion of the sky where we can just see seven stars. With one of the best telescopes 3205 stars have been seen in the same space (Fig. 70*b*). But perhaps the most interesting thing about the telescope is that it was "found out" by some *children*. Their father made spectacles. The children used to play among his lenses, and amuse themselves by looking at objects through them. Some of the lenses were thicker in the middle than at the edges. Those were ——? and

[1] Tyndall.

magnified. Some were thinnest in the middle. These made objects look less. The children found, by putting the hollow glass near to the eye and holding the other lens farther away, that on looking at the church spire they could see the vane magnified and almost within reach. Child-like they called Father to come and look. Father came (Fig. 69). It seemed to him that if he fitted the two lenses into a sliding tube, like this, it would be handier, and the lenses would keep the right distance apart. After the lesson I will let you look at the telescope. Tom Rogerson will fetch a sixpenny telescope that I have at home. I will lend it to you at playtime. You may unscrew the lenses and the tubes and look at each of them.

Now let us go on. What colour is the sun, you ask me? Sometimes the sun appears to be pure white, sometimes yellow, sometimes a dull red. It has been seen blue, by more than one person. But when the sun is high up in a clear sky it is *quite white.* The whiteness of snow, of a white cloud, or of white paper, is the whiteness of the sun's light reflected from them. The clouds and fogs are like so many coloured glasses through which we see him. Sunbeams are always pure white light—as you see them reflected from the moon, for instance. The moon is a dull, cold, dark cinder, lit up by sunbeams—a sunbeam lamp, in fact. I should like to show you how we can make the sun "set"—how the white sun appears to change his complexion. Captain Abney, the great photographer, showed this very plainly before the Royal Institution by an experiment which he called "Artificial Sunset." We can alter his experiment a little to show the same thing, by using a solution of sodium hyposulphite in our little bottle with parallel sides, placed in the solar microscope.

Now we obtain a bright image of the Sun as we see him

69.—Discovery of the Telescope. The children of the Dutch spectacle-maker, Jansen of Middlebourg, looking at the vane on top of the church spire through a convex and a concave lens, notice that the object is much larger and apparently almost within reach.

at noon above the clouds. I add a few drops of (hydrochloric) acid to the solution, drop by drop. This makes it muddy by degrees, and as it thickens cuts off, first the violet, then the blue, then the green, then the yellow rays. Now we see the sun as he sets in a smoky, foggy sky. You can see it as it is now—a dull red sunset—if you smoke a piece of glass and look at the sun through the smoke.

I told you that all light as well as all heat comes from the Sun at first. Let us just think over all the things that we get light from — I shall try in these talks to tell you something about most of them,—how they all come out of sunshine. We have said "moonlight," "candles," "lamps," "fire," "gas," "paper," "chips," "matches"—do you know of any others? To-night go into the cellar or a dark room and rub two pieces of loaf-sugar together. Also get a round glass bottle, warm it well and rub it with a *silk* handkerchief or necktie (also warmed). Both these experiments must be made in a dark room. We have learned something too about the heat of the sun. We have seen that even the few sunbeams that shine down on a lens will do some very wonderful things. But we might compare the sunbeams that we catch in this way with a drop of water out of the great ocean. If we had a burning-glass as large as the whole earth, we could only collect less than a two-millionth part of the sun's heat — that is to say, *two million glass lenses each the size of our earth* would not gather together all the Sun's fairy messengers.

I think that from what we have learned together you will agree (1) that when objects are far away they are little, and they grow bigger (or seem to do so) the nearer they come to us. (2) Lenses also make objects look bigger, don't they? So that to look at an object through a lens has the same effect as if we brought

the thing nearer to us. Now this is very important, so I want you to be quite *sure* about it. I will say it again. There are two ways of making an object look bigger—we may either draw it up close, or look at it through a lens. So that the lens does the same thing as bringing the obj nearer to us. Yes, you believe that up to a certain poi I know, but I will just see if you fully und stand it. You see me—you know just ho big I am? "Yes." Should I seem any bigg if I were to come close up to you? "No." thought you would say no. Harry, I wi take something smaller. I open this boo before me and lay it on the desk. It is ju as far from you, Harry, as I am. Can yo read it? "No." Why not? Try. The print is so smal that you can't see it three desks away, you say. Now will place it a desk nearer. Can you read it now? "No." No! don't bend over. You can see that the letters are larger than they were, you tell me. Now at one desk's distance. You can see that the letters are larger still, but you can't make out the words. Stand straight up, please. Take it on to your own desk. Now you see it distinctly; the letters are much larger. Take it up in your hand. You see it better now. Yes, now the letters are very large. Take it nearer to your eye. You can't see it? Why? It hurts your eye and the letters swim about, you say. Poor old man! Come over to the window and I will make the letters grow very much larger still, and yet nothing shall hurt your eye, for we will stop off all the rays of light that you don't use to read with. You are laughing, I daresay, but you can try it at home. I make a pinhole in this pill-box lid to protect your eye from the darts of the fairies companying those by whose help you are reading. Now,

FIG. 70a.—PORTION OF SKY. Seven stars are visible.

looking through the pinhole you will be able to bring e book *very close indeed* to the eye, and you say the tters are now very very large, like those in the big Bible

FIG. 70*b*.—THE SAME PORTION, AS SEEN WITH ONE OF THE BEST TELESCOPES. 3205 stars visible.

at home. You are amazed! Yes, it really is so!—very wonderful, no doubt, but it is only a similar experiment to mother's coming home, and the half-crowns,—carried out a little further. You evidently did not believe the

rule held good all the way! But now you will be able to tell grandfather what to do, if he should lose his spectacles!

You have all tried it now, I think, but try it again at home, for you need a very good light, *since you use so small a quantity.* Now, you can honestly admit that lenses *practically* bring objects nearer to us. Have you ever thought that the lens brings the sun nearer to us, or, if you like it better, takes us nearer to the sun? How much nearer does our largest lens—nay, the largest burning-glass ever made—take us? Just about a four-hundredth part of the way—so that when we had travelled 232,000 miles, everything we had taken with us would have melted, and ourselves—well, we had better not mention ourselves! I could not give you any idea of how hot the sun is. We have spoken of the immense size of the sun. We will suppose that the sun's surface is marked out in square yards. With the ruler, Albert, I will measure out on the floor a square yard. Now the space inside the chalk lines is one square yard. Suppose that the sun's surface were so marked out. It is calculated that the sun sends out as much heat as could be got by burning sixteen loads (tons) of coal every day on each piece of this size.

When you get into the higher classes you will learn something else about the wonderful sun. I have been tempted to tell you a great deal more perhaps than such little folks can remember. There is just one experiment which I saved for to-day. While we have been talking about the sun, he has been busy working for us. Under this glass is a piece of prepared paper. I believe I have seen some put up in halfpenny and penny packets at the toy-shops. Yes, Mary, I look in toy-shop windows sometimes, for you know I am interested in toys. Be-

tween the paper and the glass is laid a piece of maidenhair fern. The whole is pressed together in the frame by two bull-dog clips. All the paper except that which is covered by the fern is turned dark brown by the sun; underneath the fern it is still light-coloured, and so I have a beautiful picture formed. But the moment I remove the fern, the sun will darken the light parts also. I shall take it out of the light and *fix* the picture so that it will remain distinct as it is now. I shall dip the paper into some water in which some hypo-sulphite of soda, or "hypo," as the photographers call it, has been dissolved. Then you will all be able to look at it. And I doubt not you will try the same thing for yourselves.

But we might almost go on for ever talking about the Sun before we could tell all. We find him shining in our lamp and fires, growing the flowers in the gardens and fields, sailing our ships whether by steam or wind, distilling the water in the clouds by carrying up drinking water from the sea and leaving the salt behind, turning all our windmills, driving our machinery—in fact, doing all sorts of things for us every day, besides making us glad and healthy, happy and useful, by the presence of his fairy sunbeams among us.

I sometimes think we are least sensible of all animals in recognising the value of sunshine. You will have noticed that directly there is a patch of sunshine on the floor, your cat or dog will insist on sitting there. I often see them asleep in windows as I pass. Dick, the canary, takes care to let us know every time the sun peeps in—how he sings in his cage in the window! A few days ago I called on a friend. It was raining tempestuously at the time. A few minutes after, it seemed inclined to clear up,

and my friend went to the window, looked out, and said in very surprised tones, "Why, the sun's coming out!" I replied, "Well, what difference will that make to you?" He said, "*It makes all the difference.*" Then he explained that he had intended to go out and collect some insects; but the day was so dull that it was no use to think of going. Then he had arranged to be busy at home instead, and presently the rain came down in torrents; but now, he said, he should go and look for his insects, for they only came out to play when the sun shone. I asked where they went to at other times. He said he did not know; they hid themselves somewhere.

If we went to the flowers I believe they would tell a similar tale. Undoubtedly, there is a corresponding difference in ourselves when the sun is shining. We all feel it, though we may not be able to express the idea in words. "*I know.*" What do you know, Charlie?

> "I looked on the peasant's lowly cot,
> Something of sadness had wrapped that spot,
> But a gleam of thee on its casement fell,
> And it laughed into beauty at that bright spell."

Home Experiments

32. To-night of course must be given to the new magnifier, viz. the pinhole in the pill-box lid. Hold the book under the gaslight.

33. Some of you will want to print some leaves to-morrow. This little packet has printing-paper, frame, copy to print from, clips, sodium hyposulphite, and whatever else is needed. Open the packet in a dark room, or paste some orange-coloured tissue paper over the hole in the shutter.

34. Rub two pieces of loaf-sugar together in the dark.

[To-day after our story a group of children came up to me and begged me to explain more particularly how the sunbeams prepared the food of plants. I told them if they had understood the few words I said in the last lesson that I should be quite satisfied, but evidently *they* were not. So I had to parry as best I could the irresistible "Why?" of the disconcerted children. I told them that the story was a long one, cut it as short as I might, and would take us beyond the limits of our subject. They seemed puzzled beyond measure at my attitude in thus closing the door upon them, so to speak. At last I yielded in so far as to say, "You may come to me at playtime and I will think the matter over in the meantime." At playtime we put some water-cress in a glass jar and set it in the sunshine. But the sunlight was too faint to give any perceptible indication. One bright little fellow suggested concentrating the light by means of the water-lens. Another said, "Couldn't we use the solar microscope and then we all could see the image on the screen." Thus they coaxed me into promising a story to the whole class dealing briefly with the subject, and then made off with more than usual agility into the playground with a sense of victory achieved.]

CHAPTER XIX

HOW THE SUNBEAMS FEED THE FLOWERS—PART I

THIS story is given by special request, and that leads me to believe, that, even if it be a little hard, you will make an effort to follow what I say, and that you will not allow me to pass over anything that you do not quite understand.

First of all, tell me, did you ever try to grow a plant? because a little girl told me yesterday she did not know that plants required food. Plants live and grow. How do you live and grow? True, you do not feed your plant as you would a rabbit. Now the questions arise, "Who feeds the plant?" and "What does it live on?" Is its food solid or liquid? How does the plant get at it, seeing that it cannot move out of its place? It cannot go to the stores for it. "I know,—it gets it out of the earth." Not altogether, for you remember last summer we hung up a sponge in school and sprinkled nasturtium seeds over it, and you watched the little leaves shoot up day by day—you remember? "Yes, and we watered it every day." Perhaps some of you may have noticed that potatoes and onions begin to sprout when left in the cellar. Did you plant them in soil? "No, they were on the bare floor." Did they grow to any size? "No." Did they look healthy and strong? "No." What colour were the leaves and sprouts? Tell

me exactly. They were yellow, not green—in fact almost white. Did you ever have any celery? What colour is it —the best sort, I mean? Who can tell me how it is grown

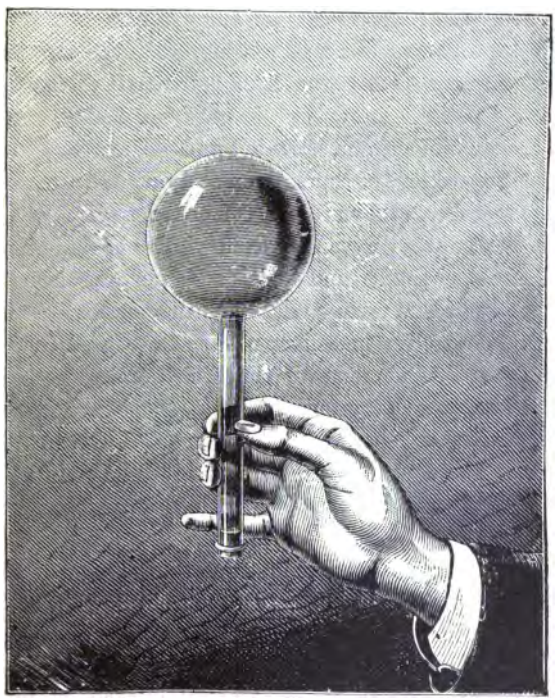


FIG. 71.—BURNING GLASS.

to make it so white? Why? You don't know. It is first allowed to grow green and strong like other plants. Then it is planted in mounds of earth to keep the sun from shining on it. We tie up lettuces and endive for the same reason, viz. to keep the sun out, and we find that the white part

has a different taste from the green. Now, can you tell me why your plants don't grow up in the cellar?

Plants must have moisture, air, some heat, and sunshine if they are to grow up and be healthy. Your cellar provided these except the last, which is the one which we are about to consider. I may say here, in passing, that the sunshine is just as necessary to the growth of you little plants before me now. You all know how bright and lively you feel when the sun shines, and how dull and miserable (*i.e.* comparatively speaking, of course) you feel on a dingy, dusky, gloomy, wet day. If you were compelled to live in cellars the roses would soon vanish from your cheeks, and you would become sickly and pale, and perhaps soon die. Fortunately in this town, and I hope in others too, people are forbidden to live in cellars now as they used to do not very long ago. But some of the little houses are built so close together that very few sunbeams get into the narrow streets, and then only when the sun is nearly overhead perhaps. These wonderful sunbeams! These busy sunbeams! Is it not a pity that people do not know them better!

But let us return to our first question, What do plants feed on? Try to answer me. Do you think they feed on lead-pencil, Lucy? Now you are laughing; you think I am joking. Do they? "No." Well, something more like it than you are aware of. Blacklead is not the right name for what you are writing with. "Graphite" is more correct. It is pure *Carbon*. Many other substances are carbon also in some other form. This piece of charcoal in my hand; the coke in the coal-box—coke, you know, is left after the gas is burnt out of coal, so that *coal* must consist largely of carbon. You see I am lighting this lamp, and you are surprised that I turn it up too high and smoke the

glass. Now I put the light out, and in a minute the glass chimney will be cold, and then I shall take it off and remove some solid flakes of fine black soot, which is called simply "lamp-black," and is used by artists for painting. See here it is, another form of carbon. Soot also is carbon. Would you like to eat this stuff? No? You are shocked at the suggestion. *Do* you eat it? You think not: you are growing cautious. What do you eat — bread? "Yes." Meat? "Yes." Toffy? "Yes." Sugar? "Yes." Well, we will take some loaf-sugar. You all know that sugar is obtained from plants. See, I will put two or three lumps on this shovel, which has been in the fire and has become red-hot. First, let me tell you *why* I put the sugar on the shovel; it is to take away the water from the sugar. The sugar appears to be quite dry, but I think we shall succeed in getting water from it. Watch! Now I shall hold a cold plate over the sugar while it is burning. See! the water appears as drops of dew, and all that remains on the shovel is a very pure black carbon.

Now, while the shovel is hot, I will put on it these pieces of bread and meat, keeping them from getting alight. You see at once that they are becoming charred or *carbonised*, and you can easily test any food yourself in this way to see if it contain carbon.

You little thought that this pretty white sugar was but black carbon and water; but what should you think if I told you the prettiest, brightest, and most valued object in the world was pure carbon? What is that? Yes, we have not yet learned how Nature makes her diamonds, but we do know they are the same substance as this soot which every one wants to be rid of.

A plant is more than half carbon. This plant I put by the stove before the lesson began, so as to be quite dry. I

must not allow the shovel to be too hot, or the carbon will burn up and leave only a little bit of white ash behind. Now that the water and smoke have disappeared, nothing

FIG. 72.—"THE COW WITH THE CRUMPLED HORN.

but this shrivelled black object remains on the shovel. It is all carbon except the very little ash that I spoke of. The smoke also is carbon.

All living matter will burn up so. I once knew a little girl, about as big as you, Ethel. She had a bad habit of

standing on the kitchen fender to look on the mantel-piece. Often her father and mother warned her that she would some day be burnt to death, and one day she actually got a hole burnt in her frock by a falling cinder, and I think she was more careful after that. Her little brother used to tease her, by saying that she would be burnt to a cinder, and sometimes he even doubted if a cinder would be left to tell the tale; and indeed it is true that we ourselves are very largely built up of carbon. Perhaps that accounts for the lustre of the little gems in this room! Every day a grown-up person breathes out three pounds of carbon—not in the solid state like this piece, but as I shall explain in the next story. You will not wonder, then, that we take food containing carbon to make up for this loss.

Home Experiments

35. Get a clean round bottle and a piece of silk, or a silk necktie; make both very warm by holding in front of the fire, and rub them together in the dark.

36. Take a piece of flannel or fur and warm it, then rub an indiarubber comb or a stick of sealing-wax with it, in the dark.

37. At home I want you to test, as we did in school, whether things contain carbon. All substances that char when heated contain carbon. Make a list showing each substance that you test, and say whether it belong to the animal, vegetable, or mineral kingdom.

You can char *a few* substances by using your bulb (Fig. 71) as a burning glass, on bright sunshiny days.

CHAPTER XX

HOW THE SUNBEAMS FEED THE FLOWERS—PART II

Do you remember that windy day last week? What day was it—Thursday? "No, Friday." Ah, some of you were chasing your hats down the lane when I saw you, and one boy whom I noticed amused me very much, for the wind carried him nearly "off his feet," and despairing of walking in the ordinary manner he turned round and walked backwards towards school. What fun the wind does make for us every now and again. Every one is very smart and lively out of doors, and those who watch the performance through the windows have many a good laugh at the passers-by. What is this wind? Where does it come from? Could you make some? How would you do it? Louisa would get a pair of bellows, she says. Freddy is before her, for he is wafting the door rapidly to and fro. You would be invaluable in an over-crowded concert-room, Freddy! Without getting up from your seats, children, show me how you would make a gentle breeze. Yes, that will do now, or you may spoil your exercise-books. Ah, there is little Jim blowing with his mouth—well done! But what is it that you have been doing? You appear to have been moving something, judging by your actions, and yet I have not seen *anything* move. What did you stir to

make such a draught? The *air*, you say; then why did I not see it? Had you sent a *ball* to and fro, for instance, I should have seen it move. You are right, the air is invisible, but it is there all the same, though we are apt to forget all about it at times.

Fishes live in the ocean; I wonder if they forget that the water is there! We live at the bottom of an *aerial* ocean, or ocean of air. Just as the fishes live at the bottom of the water ocean. Neither kites nor balloons nor birds ever rise to the surface. What is air? I told you that I must cut my story short, so I shall merely say that it is a gas called oxygen—a strong active gas that would make us live too fast were it not very much diluted. You know what a quantity of water mother puts in your tea to make it weak? We dilute a gas, not with a liquid, but with another gas which has not much character of its own, and corresponds in this respect with the water in the tea. So now you know that we live at the bottom of an ocean of weak oxygen—keep that well in mind! Who is it that has a flower-holder? Some one had a little glass tube with a rose in it. Thank you, Maggie, will you lend it me? If I break it, can I get another for you?—yes? "It cost a penny." Well, I don't expect to break it, and I am sure you will prize it the more after it has helped us. We must have the tube perfectly dry; for that purpose, I hold it over the spirit-lamp, so. Now I take this piece of paper and fold it lengthwise several times. Not to light the gas with? No. I shall make a holder for my tube, so. I put the tube in the middle of the band, and then twist the ends like the handle of a toasting-fork. Now I put a very little of this red powder in the tube. Read the label on the bottle, "Red Mercury Oxide." This powder contains just two things; I think you might tell me from the name what they

are. "Mercury and oxygen." You are right. Many other substances contain oxygen, but this experiment possesses an historic interest, as it was from this substance that the chemist Priestley discovered oxygen in 1774. I heat the

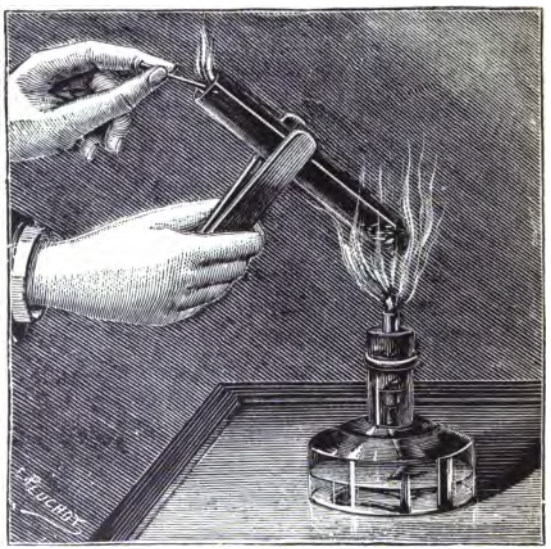


FIG. 73.—RED MERCURY OXIDE is heated in a small tube over the flame of a spirit-lamp. Mercury is left behind in the form of a circular mirror on the cool part of the tube. Oxygen (a gas) escapes into the air. *It will relight a glowing match.* Do you notice that the tube is held by wooden tongs (peg), and that the lamp is made out of an ink-bottle?

powder. Presently you will see the red colour change into a dark grey and then into liquid metallic mercury, which you will remember to have seen as a silver thread in thermometers and barometers. Oxygen is a gas and will escape into the air. Now watch! I light this match and let it burn for a moment. Do you observe that a glowing

bulb is forming on the tip? I blow out the flame and plunge the "spent" match into our little tube. There, it is lighted again. Shall I blow it out? "Yes." Again it is re-lighted in the oxygen (Fig. 73). See, a bit of the charred end—which is nothing but charcoal—has dropped into the tube and is burning most brilliantly. When all the oxygen has escaped I shall show you the mercury first as a mirror on the inside of the tube; then I shall empty the tube so that you can see it roll about (Fig. 74). All substances which burn in air do so with very intense brightness in oxygen, and

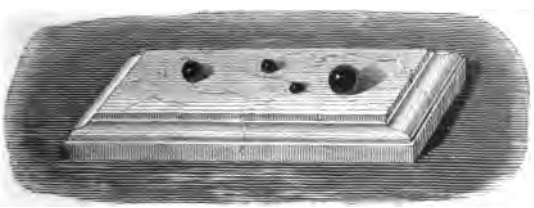


FIG. 74.—MERCURY OR QUICKSILVER.

in so doing join themselves to the oxygen and form new substances quite unlike either of the originals. The carbon in the tube uniting with oxygen forms a new gas, so heavy that it will drop into this tiny bottle which I shall hold beside it, thus. Into the bottle, which you can see is quite clean and bright, I pour a very little of this clear liquid which is labelled ——? "Lime-water." Now I hold the tube and bottle side by side for a moment. Then closing the bottle with my thumb, and shaking up the lime-water, I find it is no longer clear like water but seems to have had a drop of milk spilled in. This milkiness is nothing else than chalk, such as we use for the blackboard. The chalk is formed by the lime joining with this new gas—*Carbon di-oxide* by name. This we could easily prove by filtering the milky

liquid through blotting-paper and drying the chalk which would remain on the filter-paper.

Now I pour some clear lime-water into this clean tumbler, and also some in this saucer. One of you may breathe

FIG. 75.—FILTER OF BLOTTING-PAPER.

gently down this tube into the tumbler. Come and stand before the class, George. What are your hands up for, children? He's making chalk, you say. Do you think he will make enough to write on the board with? When he

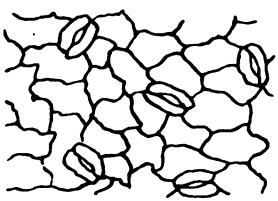
has made a little more we shall pass it through this filter of blotting-paper and dry it (Fig. 75). Do you remember what chalk is composed of? "Carbon di-oxide and lime." Right. Where has the carbon di-oxide come from this time? Now you are puzzled. Yes, it has come from George's breath. All animals (don't look so shocked! human beings are animals too)—all animals make carbon di-oxide, and breathe it into the air. How do they do it? Unconsciously—that means, without knowing it. The carbon which they eat joins itself to the oxygen that they breathe. We saw that iron and oxygen made iron-rust: carbon di-oxide has been called *the rust of our bodies.* Thus the carbon and oxygen, joined together in the form of an invisible gas, is carried about in the air, and thoroughly stirred up in it. Now here is carbon, the plant's food, wafted about its head, and yet the plant cannot get at the carbon because it is joined fast to the oxygen. Is not that tantalising?

"Wanted,—a good little fairy to come and unlock the carbon from the tight grasp of the oxygen so that the plant may not starve in sight of food." That is the way the problem would be solved in a story-book, would it not?

Nature's is the most wonderful story-book that ever was written—the fairies in books are clumsy creatures in comparison. Nature—"the dear old nurse, who sang to Agassiz, night and day, the rhymes of the universe"—has still more wonderful songs to sing, and still more wonderful tales to tell, unheard as yet by any human ears. She has an inexhaustible store, for those who accept her invitation—"Come, wander with me, into regions yet untrod."

On the under surface of this leaf are thousands of little mouths (Fig. 76), so small indeed that an apple-leaf

contains one hundred thousand, while a lilac-leaf contains a quarter of a million in every square inch of its surface. Through these little open lips, which look so like two kidney beans, the air containing carbon di-oxide enters into the leaf. Here the carbon di-oxide meets with a number of little round bladders filled with a kind of paint, called "leaf-green" (*chlorophyll*), and when the sunbeams join them the work begins. How? Nobody quite understands the whole process. First, the sunbeams play



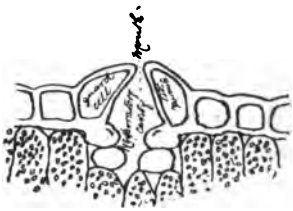


FIG. 76.

a, Stomata or breathing mouths.

b, A mouth (more highly magnified) showing guard cells which open and close the mouth.

upon the leaf and set it tingling all over. The green rays dart off back again, as we said before. The other rays penetrate into the interior and there meet the carbon di-oxide in the green cells. They turn out the oxygen, and set free the carbon. Here are the sunbeams doing work by undoing previous work! The carbon at once joins itself with the sap, which the plant has pumped up out of the soil through its roots, and becomes food which shall nourish the plant and cause it to grow healthy, strong, and green. This change takes place *only in the sunlight*, and chiefly in the *green* parts of plants, though these *stomata* or mouths are sometimes found where you would

least expect them—for instance, in the brown skin wrapped round the kernel of the walnut.

First I will show you how to make this experiment at home. Put leaves of any kind into a tumbler and turn it upside down in a saucer of water. I would advise you to draw a bowl of water and take your tumbler and saucer down below the surface before you turn it over. If you should get a bubble of air inside you must try again. Those near, will see now and then a tiny bubble, sometimes two or three, running races up the tumbler. I went down to a pond last night and gathered this plant (*potamogeton*) which grows over head in water. It gives off oxygen very rapidly when the sun shines on it. I put this water-weed in a tumbler and cover it with my glass funnel, and place on that this flower-tube filled with water[1] (Fig. 77). There is always a little carbon di-oxide dissolved in water. The plant separates this; but *the action goes on faster* if we introduce a little more. Tim, take this tube and breathe into the water.

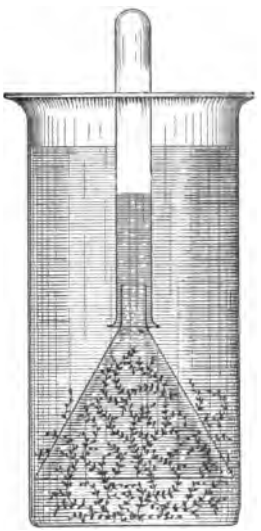


FIG. 77. — POND-WEED (*potamogeton*) gives off oxygen in abundance.

[1] (1) When a large object is to be projected by the solar microscope, the lens (objective) must be larger than our pocket-lens; or (2) use the pocket-lens as before, but place the object on the other side of it, viz. between the lens and the screen, on which will appear a sharp shadow. This latter is an excellent method for projecting experiments.

Now put the tumbler in the solar microscope, a little nearer to the condenser than you would a micro-slide. (With the help of smoke from touch-paper you will always find the right spot for your object—as far away from the globe as you can put it, and yet have the whole object brilliantly illuminated by the rays passing *through* it, but none passing over or under.) Then draw up the pocket-lens. See how rapidly the bubbles are coming off. The tube is full already. With what? This glowing match will tell us. It is ——? "Oxygen."

FIG. 78.—CANDLE TEST. Inside of room, door *slightly* opened. The *cold air* rushes *into* the room near the floor, therefore the candle-flame is blown inwards at *a*. The *heated air* rises to the top of the room, and escapes at *c*, therefore the candle-flame is *blown outwards* at *c*. At *b* the flame is *steady*.

Now you have seen the plant at work. The oxygen is sent back into the air for us to breathe; the carbon is used by the plant to make food, as I said before. I ought to tell you that this carbon di-oxide is an unpleasant gas. There is always a very little present in the air, as you may see by this skin which has formed on the saucer of lime-water while we have been talking. Pass it round without shaking, then we will pour the contents into a tumbler and shake it. This is the gas which makes us feel sleepy and dull when we open the door of a railway carriage where a number of people have been *shut* up together "spoiling" the air. It is our business to get rid of this "closeness," as we sometimes call it. How do we do that? "By opening

the windows." Right. For this reason plants are useful and necessary to us in order to keep the air pure; and this is why parks and recreation grounds are so important in the midst of large towns, and why we plant trees along the footpaths. At least it is *one* reason.

Home Experiments

38. Gather leaves and look at the under side with your pocket microscopes. Also put them in the solar microscope at school.

39. Charcoal is made by burning wood in a smothered way, *i.e.* without allowing much air to get to it.

Take a tin saucer or dish, fill it with sand and push some bits of wood overhead in it—some matches without heads will do. Put the dish in the oven, when the oven is very hot, and bake the wood.

40. Take a lighted candle and place it on the floor between the door and the fireplace; look whether the flame points to the door or to the fire. Now open the door a little and put the candle on the floor close by; see whether the flame points to the fire or outside the door. Now stand on a chair and hold the candle near the top of the door; notice where the flame points to. What does this show (Fig. 78)?

CHAPTER XXI

A CAMERA OF OUR VERY OWN—PART I

I PROMISED to tell you something about the eye, and to-day I shall try to redeem that promise. Yes! You know—you are sure—you know everything that is going to happen! You saw Charlie Fisher, the butcher's son, bring an ox-eye for me, and you made him tell you what he had got there. Bring it, Charlie! You observe that the eye is not unlike an egg in shape, and like the egg it has a very thick, tough, white coat, though it is not made of the same materials as the egg-shell. At the narrow end is this white string—the most wonderful part of all. It is the optic nerve which carries the messages Light sends to the brain (from which this portion has been detached). Outside you see this hard, thick, bluish-white coat, which is transparent in front so as to allow the light to enter.

The transparent part is called the cornea, which name suggests that it is hard and horny like a corn, which is another illustration of how the white opaque skin becomes transparent. All the outer coat is extremely hard. I could not harm it with my fingers or a pair of scissors. If we were to take off this shell or coat we should find underneath a soft, thin, delicate membrane, a network of blood-vessels embedded in a kind of dark-brown paint.

You can very easily guess the use of the paint, for by this time you quite expect optical instruments to be black inside. This prevents internal reflection. The front part of this coat is made still darker by loose folds (*z*, *z*, Fig. 79) which extend for about quarter the way inwards. On the inside of this under-coat is spread out an extremely thin delicate screen woven

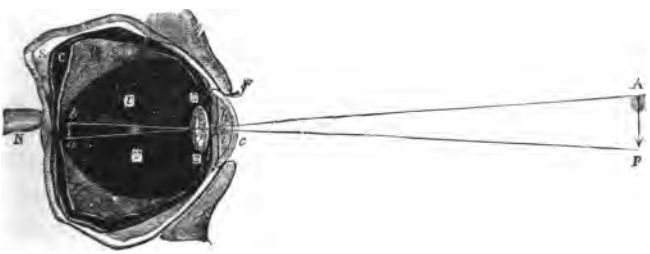


FIG. 79.—A CAMERA OF OUR VERY OWN. (The three coats are laid back to show the interior.) The darkened chamber is globular, and is made of a thick strong white substance (*sclerotic coat*) S; and is lined with a delicate coat of winding blood-vessels, covered inside by dark paint (*choroid coat*) C. The innermost coat (*retina*), R, is a tissue of nerve-fibres—the expansion of the *optic nerve*, N. The apple of the eye is not empty like a photographic camera; it is filled with a transparent jelly as clear as water (*vitreous humour*), *v*, *v*. The lens of the camera is represented (1) by the curved window of horn (*cornea*), *c*; and (2) by the *crystalline lens* (*o*) of varying curvature. It is covered by a curtain (*iris*), *h*, *i*, which is perforated in the centre by a round hole (*pupil*), the edges of which are in contact with the front of the lens. The lens is held in its place inside the eye by the plaited ruff, *z*, *z*.

of little threads or branches of the optic nerve which we were looking at. This delicate greyish curtain, called the retina, is transparent while the animal lives. The portion at the back of the eye *only*, is sensitive to light. Now I wonder if we shall be able from our description to make an eye. Here is a small Florence flask holding about 2 oz. This shall be the eyeball. What shall we call the long neck? "The optic nerve." Yes, I don't mind, if you will correct the proportion from the eye we examined.

Turning up the flask we see a little hollow that will be useful. The interior of the eyeball is filled with a transparent sticky substance which is very like the white of an un-boiled egg. We shall fill our flask with pure water and fit the flask with a cork. We turn the flask over, and into this hollow we will put the little double convex lens that we used before. I need hardly tell you that the real lens in the eye is not made of glass, though it is perfectly transparent while the animal lives. Were you to cut it through the centre so, you might mistake it for an onion. I will cut this onion through to show you what I mean. You see it is composed of a number of shells, so to speak, inside each other (Fig. 81). We shall see that this arrangement gives it more freedom to alter its shape so as to do duty for several different lenses.

What colour are Mary's eyes, Freddy? "Brown." What colour are Freddy's? "Blue." That is strange! Let us see how that is. Let me look! Right in the centre is a dark spot, almost black, and outside that is a pretty coloured circle of rays. Yours are blue. Look at your neighbours': some have brown, some grey, some blue. This is the *pretty* part of the eye—the part that we allude to in speaking of the colour of the eye. It is called the iris, which means the rainbow. Who has heard that name before? Yes, as the name of a flower. Right. You will find a similarity too if you will examine the flower next time you see it. I have tried to colour this disc something like the iris; the back is brown, as you would expect to find. We will fix it in front of the lens, and then place this watch-glass outside all for the ——? "Cornea." Right. Before we put the coats on the eyeball I want you to look at this funny thing. It is a large empty cotton-reel. I have made the hole wider with a file. Now I put half of a small indiarubber ball

over it for a cap. I prick a hole in the centre of the ball and put it over the hole in the reel, and hold it there by grasping the rubber behind in my hand. I can stretch the rubber and make that hole bigger and bigger still, and keep it quite round at the same time. See! This indiarubber represents the muscle called the Iris. The hole in the centre is the Pupil. You seem very much amused at the term pupil. Robert, come and look in the centre of Emily's eye. Don't you see a little boy there? "Yes." The word pupil means a little boy, so we call that part of the eye, where the little boy is seen, the pupil. In your eyes the pupil is round. Cats' eyes have oval pupils.

Have you ever noticed on going suddenly into a well-lighted room that your eyes could scarcely bear the light? Harry, come here. Close your eyes for a moment. Now observe the pupil when he opens them again. Open your eyes! Did you see that the little black hole was very large at first on opening his eyes, and then immediately became quite small. Now it is almost a speck. If you will take him into that end of the room farthest from the window, where the light is weaker, the pupil will grow large again. You can try it among yourselves at playtime, or at home with a hand-mirror held at various distances. What is the meaning of this? Simply, that when the light is dim, the iris makes the hole (*pupil*) larger, so as to catch more rays; and when the light is strong it makes the hole smaller, so as not to daze and tire the eye with too much light. You were much interested in the telescope and wondered how it acted. Now I can tell you the effect. It is as though the pupil opened wider and wider than is possible now. Suppose instead of the pupil being as large as a threepenny-bit we could make it as large as a dinner-plate, then we should be able to see as through a telescope. Now we will put on

the coats. What shall we put on first? "The retina." Right. What can we find to represent it? Very thin white tissue or transparent paper will do very nicely, Mary. What goes on top of that? "Some dark-brown tissue-paper." Yes, but it should have that network of blood-vessels and nerves painted on, you remember. You will supply those mentally. Now for the white of the eye you must have some thicker white paper. There are two defects in our eye, not to mention others. First, in the real eye the optic nerve enters not quite opposite the middle of the cornea, actually it is a little nearer to the nose; second, the space between the lens and the cornea is filled with a fluid very like water.

Now we will consider this eye to be a camera like those little pill-box cameras of yours, or that larger camera, the class-room; especially when we fixed the lens in our black blind, for the lens gathers up the straggling rays round the edge of the hole and makes them pass in also. The more rays we can make shine on a particular place the *brighter* it is and the clearer is the picture. The hole in the blind represents the pupil, that is quite certain. What corresponds with the iris? Yes, the iris is the blind itself, in which we make a hole of any size. Our pocket-lens stands for the "crystalline lens," and our screen at the end of the room does duty for the ——? "Retina." Right. It receives an inverted image of the objects. I will draw a diagram on the board showing an eye as it would look if it were cut in two so that you could see the inside. I shall make the eye looking at an arrow held up in front (see Fig. 79), and you will understand, I am sure, how the rays cross in passing through the hole (pupil) and produce an inverted (upside-down) image on the retina. I shall not merely rely on this drawing, though. You must see it for yourselves.

First with this model we have made. Then I shall further prove it by paring away, under water, the outer coats at the back of this ox-eye, and fixing it into a hole in the blind. If I should happen to tear the retina, which I certainly shall, unless I am very careful, I must hold up my ground-glass screen, then you will see inverted, the objects the eye observes as it looks out of the window.

If I had time I would tell you something that I read as true, though I will not vouch for the truth of it. It was to the effect that the Chinese are in the habit of telling the time of day by looking at the cat's eyes. At twelve noon, when the sun is very powerful, as we say, the pupil is a straight line. As the day wears on and the light is less strong, pussy gradually opens the pupil wider to gather in more rays. So that by always taking particular notice of the eyes of their cats, the Celestials have no need for any other clocks. You can think it out for yourselves. Would it answer on dull days, think you?

Home Experiments

41. Make a model of the iris with an empty cotton-reel and half an indiarubber ball. In the other half ball make a slit instead of a round hole. This will stand for the iris of the cat. Look at pussy's eyes at different times of the day. See if you can guess about what time it is. When will the pupil be largest? When will it be simply a dark line?

42. Can you make a model eye with your glass bulb (reading-glass), a transparent stud or bead, and tissue-paper?

43. I want you to look down the streets you pass on your way to school in the morning. First you will see a small portion of the further side, gradually a little more, then the whole. A portion of the other side now comes into view, as the former slowly vanishes. In this way the street appears to turn on a pivot. Find out all about it to tell me.

CHAPTER XXII

A CAMERA OF OUR VERY OWN—PART II

You remember I told you that our model eye was not quite correct, because the optic nerve does not enter exactly opposite to the cornea. The spot where the optic nerve enters the eye and spreads out its branches to form the retina is quite insensible to light. An image caused to fall on that spot is not seen at all. This you shall each prove for yourselves. The spot on the retina where images are most clearly seen is *yellow*, and is exactly opposite the centre of the cornea. I daresay you noticed in the ox-eye that the middle of the picture was very distinct, and the edges were much more faint and "sketchy."

Now you shall try to cast an image on the *blind spot*. Mariotte, who discovered this, amused Charles II. and his courtiers by showing them how they might see each other with their heads cut off. On your slates make a little cross.

Three inches to the right, in the same straight line, make a circle and shade it. Shut the left eye and look steadily at

the cross with the right eye. Hold the slate at arm's length, and draw it slowly nearer. At about your ordinary reading distance the circle will vanish, and will reappear when you bring the slate nearer. With a little practice the images of much larger objects may be made to fall on the blind spot—viz. the face of your companion at about two yards' distance. The blind spot is large enough to blot out from sight eleven full moons, if placed side by side! While you try that I will put a larger object for you to lose sight of. Those who have succeeded in the experiment, hands up! That is very good. I am going to call one or two of you out to try this, which I shall leave on the board for you all afterwards.

You see I have made a small *shaded* circle on the left, and a little lower down, 2 feet to the right, I have made a very large white circle which measures 3 inches across. Now, Robert, stand opposite to the little disc. Shut your left eye, and keeping the other fixed on the smaller circle, walk backwards until you lose sight of the circle on your right. That will do! You are now a few yards away from the board. The image of the large disc now falls on the blind spot. Are you sure you don't see it at all? Very good! In the same way, you see that it would be possible to lose sight of objects as large as a man's head.

The interior of the human eye is not so clear as you may be inclined to think. Some of you may have seen, at different times, matters floating before your eyes. These are mostly shadows of spots and fibres in the lens. By looking at a bright star, through a hole made with a fine needle in a card, or in your pill-box camera, you may see them, and by moving the same a little from side to side, we may obtain a well-defined image of the blood-vessels of the retina. This shadow is similar to Fig. 80, but very

much enlarged. You never thought you could see the inside of your own eyes, did you?

You have found your penny bulb to be an excellent magnifier, but it has this disadvantage, that only a small part of the object is distinctly seen at one time. All round this centre the image is "mixed up," as Robert calls it. If you will think about the matter, you will understand in a moment why this is. The focus of your bulb is at about half an inch from the glass surface. Now when I hold a piece of printed paper, or any flat surface, near, only a very small portion is half an inch distant from the glass. But now if I bend and curve the paper, I can bring more of it into the right position. Here is an orange; I cut round the peel, so as to remove half of it in one piece. You see I can fit it again on the orange like a cap. Look at it; it is not a flat piece; it bulges out on the coloured side; it is hollow (*concave*) on the white side. It is everywhere

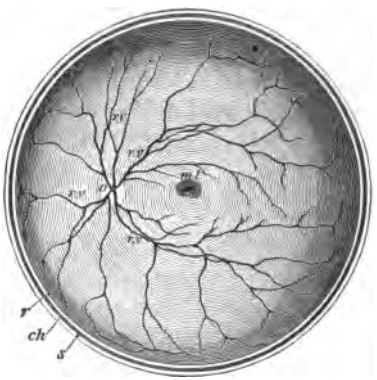


FIG. 80.—OUR OWN CAMERA—THE SCREEN.—The back half of the eyeball seen from in front. The retina is spread over the concave surface. Where the optic nerve enters (*o*) there is nothing but nerve-fibres and blood-vessels (*rv*). There are other gaps, too, where no image is seen on account of the blood-vessels, for these shut off the light, and make shadows on the surface immediately behind them, which is really the screen on which the images that we see are formed. Blood-vessels do not interfere with the yellow spot, *ml* (*macula lutea*). In the centre of this spot the retina is *very thin* and *pressed in* a little. We see objects *quite distinctly*, only when the image falls *exactly* on this spot. Corresponding with the rim of peel seen round half an orange, notice the coats of the eye, the retina (*r*), choroid (*ch*), sclerotic or white of eye (*s*).

equally distant from the centre of the orange. Look now at the screen of the sunshine recorder (Fig. 67); has it not the form of a strip of orange-peel? I daresay you will wonder why there is not more of it. That is because no more is required to record the sunshine in this part of the world. Look again at the orange-peel. Look at the white curved surface; in such a way does the retina spread over the inside of the back of the eye. If I were to cut the orange in two, leaving the peel on the other half, so, and ask you to look through the pulp at the white lining, you could not see

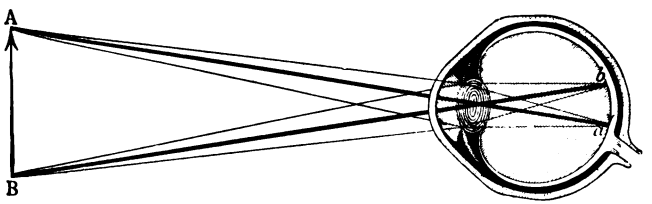


FIG. 81.—A small inverted *curved* image, *b*, *a*, of the arrow, A, B, is formed on the retina. The rays which come *from the point* A are so broken (refracted) in travelling through the eye, that *they all unite at a*, while those from B *unite at b*.

it. Look! But the jelly which fills the inside of the eye is transparent, and if you looked through that you would see what is here (Fig. 80). You see, too, how the rim of orange and white peel is here represented by the coats of the eye.

An arrow placed in front of the eye (Fig. 79) causes a small inverted image on the retina. This arrow is usually represented in a *vertical* position, as here; but it is clear from what we have said and seen, that the image is formed *on the concave surface of the screen itself*, and not in front of it. The correct form of the retinal image is shown in Fig. 81. You can easily prove this for yourselves by taking a pin and placing it, so, against the peel of the half-orange.

You may make it stand erect *in front of* the white screen, but you will have to *curve the pin* to make every part of it rest *in contact* with that surface.

I shall now endeavour to show you that each eye sees a different picture. They are not both in the same place. Shut your left eye. Hold your left hand with the fingers pointing upwards, so that the first finger covers the others, and you also see the palm. Now open the left eye, closing

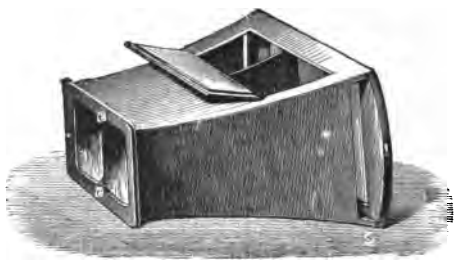


FIG. 82.—BREWSTER'S STEREOSCOPE.—Two slightly curved prisms, with their thin edges meeting at *e*, *e*, form the double eye-piece through which the pictures inserted in the slot *s* (in front of a ground glass pane) are seen somewhat further off, somewhat magnified, and at the same time overlapping each other, so that both appear *as one* in the middle of the instrument. *In reality* each eye sees only the one which belongs to it.

the right. You will see only the back of the hand. A little practice will enable you to get the exact position described. These views represent the images seen on the retina of each eye. If the pictures at the back of the eye could be looked at through a prism by another person standing behind, they would come together, so that the objects would seem to stand out and *appear solid.*

I have brought this *stereoscope* (Fig. 82) for you to look through at play-time. In it we place pictures drawn just as seen with each eye. We then look through a prism (or clined mirror), which gives the rays of light the same direc-

tion as if they came from a single object. You shall watch me make a stereoscope on the first opportunity. I daresay you will wonder how these pictures can be made, and will be inclined to ask if the man shuts one eye while he draws them. These pictures require to be very carefully made, as the least fault would quite upset the arrangement. To obtain them quite exact we must employ our artist, the Sun. How? That is right, Charlie, get the sun to photograph them. The photographer's lenses must be exactly alike, and as it is impossible to make two lenses alike even out of the same glass, one lens is cut exactly in two, and the halves are placed at a distance of $2\frac{1}{2}$ inches, which is about the distance between our eyes. This camera, with its *two eyes*, so to speak, makes the two pictures you see here (Fig. 83). Put them in the stereoscope and look at them. Now try the effect with these two coloured papers. You do not see either colour, but a kind of "shot" appearance.

The eye is not a fixed rigid mass like this lens. If it were, we should be able only to see objects distinctly which were a certain distance from us, as you found was the case when you tried to read with the glass lens. The lens within the eye alters its shape, by becoming flatter or rounder, as we view distant or near objects, respectively. You will readily understand that however quickly this change takes place, it is impossible that the lens can be *both* round and flat *at the same moment.* Now I place this card on the easel before you, a little distance away. Take up the piece of muslin or net which lies on the desk. Through this veil you can read the card. As you read the card, you lose sight of the veil. When you see the veil plainly, you lose sight of the card. Is it not so? You cannot see both at the same moment.

There is another peculiarity about the eye, too, which

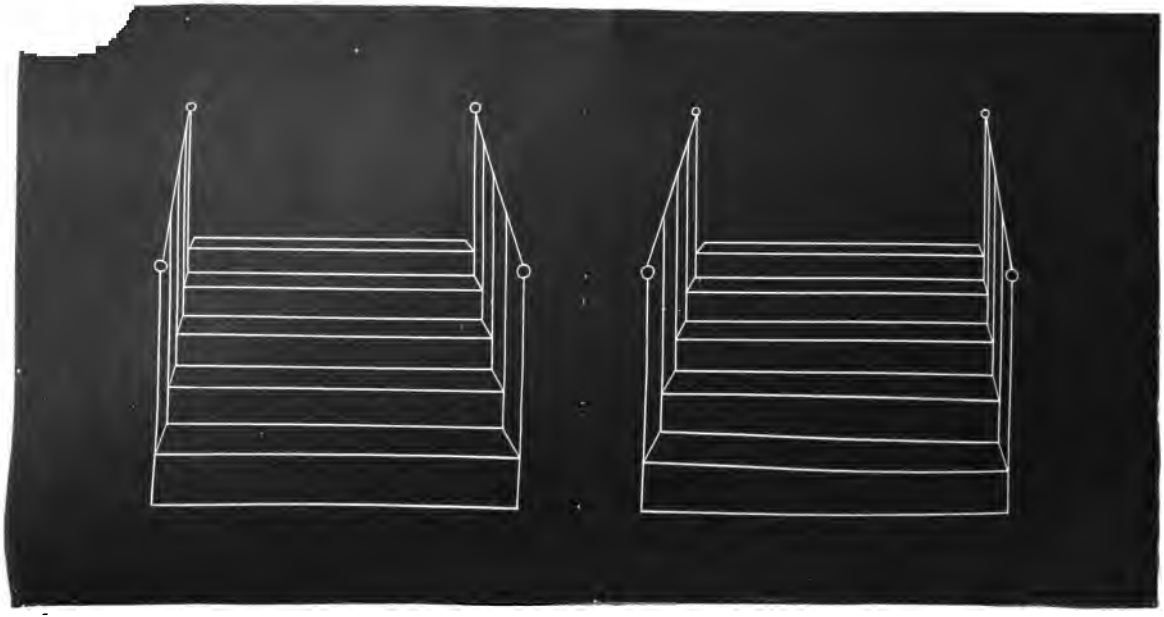


FIG. 83.—STEREOSCOPIC SLIDE.

A. *Left-eye view*—With the left eye we see more of the right side of the picture, and less of the left.

B. *Right-eye view*—With the right eye we see more of the left side of the picture, and less of the right.

I. Measure the distance between "*identical points*" in the two views:—(*a*) *Centre*—From middle of third step in A to same point in B (this corresponds with the distance between our eyes). (*b*) *Foreground*—Any point, say the left front corner of bottom step in A and B. Is this greater or less than the *Normal* (*a*)? (*c*) *Background*—Any point, say same corner of top step. Compare with (*a*). *Caution*—Do not measure from the *right side of A* to the *left side of B*.

helps you to enjoy your fireworks. I saw a boy the other night whirling round a piece of tarred rope. You know the effect. He seemed to make a fiery circle. Now the end of the rope could not be in *every part* of the circle *at the same* moment, could it? How can you explain that? The pictures on the retina are not *rubbed off*, so to speak, as quickly as the rope goes round, so that we see a whole series of pictures at once—just as though Light, the photographer, were so sharp in taking the likenesses that his assistant who removes the finished pictures could not keep pace with him.

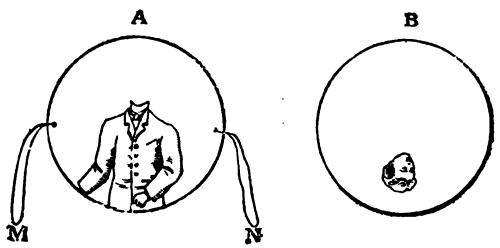


FIG. 84.—THAUMATROPE (wonder-turner).

See, I twirl round this stick, the end of which has been in the fire for a moment. Your pin-wheel is seen as a circle of light for this same reason, although, if it slacken speed, as it sometimes does, you can watch the lighted end travel round. This fact also explains why a rat is seen inside this cage. The rat is drawn on the front of the cardboard circle, the cage on the back. Twirling it by these two strings, the pictures succeed each other so quickly that they appear as one. You can buy the pictures in sheets at the toy-shops. Be careful in mounting them; one side is inverted. Here is the figure of a boy; he is beheaded,

but all comes right when you twirl the string, for his head is on the other side. Trace over this, and mount the same on a card (Fig. 84). Here you see an improvement in this figure of a man drinking out of a bottle. A little more skill is required in twirling. At the right-hand sides of the cards, when placed together, there are two "strings," or rather there is a piece of twine and a piece of elastic. Holding both string and elastic in your right hand, you can stretch the elastic a little, and produce the different stages of the act, so.

The zoetrope, which I used to show you to illustrate how you should come to school in the rain, is on the same principle, and as it can be bought for sixpence, and has caused you so much entertainment already, I need only mention it in passing. The coloured papers you put on your tops illustrated the same principle.

Take out your slates. Draw me a picture of a very heavy shower, with the rain coming down in torrents. "Must we put a man with an umbrella?" Put as many people as you like; remember I want to see your drawing in two minutes.

Joseph, what is yours like? What! after all our talk about the rainbow, don't you know the shape of a raindrop? Nora, don't rub anything out! I'll come round and look at all the slates before I criticise any further. You've all done the same thing! You tell me a raindrop is the shape of your burning glass, and yet you've drawn them as if they were little needles dropped from a packet! What can be the reason? Arthur says the rain comes down so quickly that it looks just like his picture. What do you think about that? Well,—Fanny? You are quite right, children! In drawing, we represent objects, not as *we know that they are*, but according to what they "look like" to us.

We have a picture in the zoetrope showing what a shower looks like.

I have here two papers, one white and one black, which I shall pass round for you to look at. In the centre of the black paper is a small square of white; similarly on the white paper I have pasted a black square. The question is, which is the larger, the black square or the white? Examine them very closely, and write the answer on your slate, but "don't tell!" Now we will take the answer. Those who have written *black*, hands up (*nobody*). White? (*all*). Well, children, each is exactly a square inch. Our eyes deceive us as to the size of *very bright* objects, especially *if small*; they appear very much larger than they really are. To prove this, I have a piece of thickish wire in the fire; when I take it out I expect we shall find that the white-hot end looks much thicker than the cooler part. I tell you what to expect, because the wire cools very rapidly; the thinner the wire is, the better the effect, as you may prove for yourselves. Even with the poker it is noticeable.

This peculiarity of the eye in magnifying brilliant objects is called *Irradiation*. I know of no better example of it, than, that the narrow crescent moon, a few days old, appears to most people, if looked at steadily for a moment, to be double, or even treble. Look out for this, please, and tell me when it is to be seen.

There is another experiment which I should like you to make. I want you to see the effect for yourselves, before I explain *why* it is. It is one that requires more room than we have here. I have cut some little squares of violet glass. I shall lend you each one to look at the street lamps through.

I must now refer to those questions you put to me, and which I promised to answer to-day.

1. How is it that we can see the cat's green eyes in a dark room?

2. Why is it that the cat can see in the dark?

I will take these two questions together. First, there is just a little light in your dark room, and pussy is able to make the best of it. In place of the black paint that I spoke of in the human eye, she has a mirror-like surface which reflects the light, so that we see pussy's eyes by the few rays which have entered her eye by the pupil, and have returned to us after reflection.

3. Why is the pupil of our eye black?

Partly on account of the "paint" within, and partly because when you look into your neighbour's eye, your head screens off the rays of light which would otherwise enter through the pupil. If you were to reflect light into the eye, by a mirror with a hole in the centre, say one of your little discs that I gave you, and looked through the hole, you would see the interior of the eye lit up. A watch-glass coated with tinfoil, except in the centre, would be better. This is the principle of the Ophthalmoscope, an instrument for seeing if the eye is in a healthy condition (Fig. 85). The patient stands behind a blackboard or screen, which shuts off the light of the lamp. The lamp sends its light on to the mirror or disc which the doctor holds in his hand. In the other hand you see he is holding a lens to magnify the eye.

What does the doctor see, you ask. He sees the pupil glow like a live coal; he sees, too, the inside of the eye of a reddish colour, with the darker branching object shown in Fig. 80.

4. You don't think we do see two pictures—one with each eye? That I can easily prove to you. Look at me while I press one eyeball a little towards the nose. Now

how do I look? "I see two teachers side by side, how funny!"

5. If the images on the retina are upside down, how is it that we see objects right side up?

There have been many explanations given, some one of which may be the right one. The matter is still a mystery

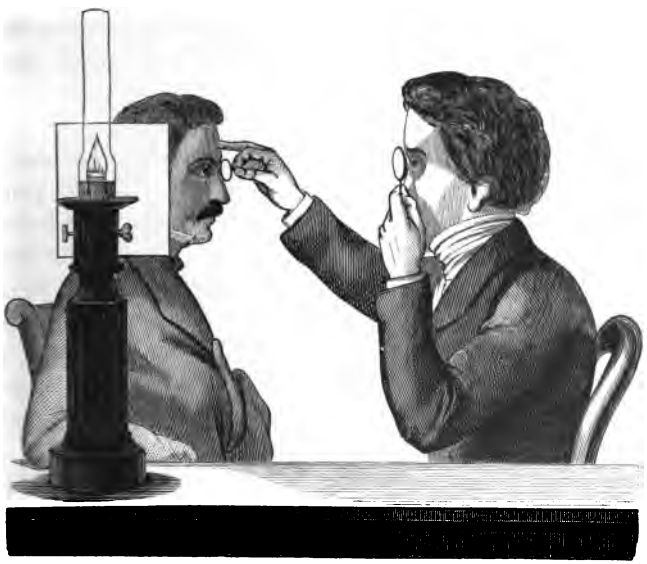


FIG. 85.—OPHTHALMOSCOPE.

which perhaps you may be able to solve when you grow up. After all, it is not our business to trouble overmuch about the messages which Light sends to the brain. The brain is often compared, you know, to the master in his counting-house; in whatever language the message is delivered to him, he always sends us a reply that we can understand. Let me illustrate this point. About twelve

months ago I was talking to a friend of mine in one of the London post-offices. I had been examining the instrument on which she so cleverly sent messages, and had satisfied myself that I understood its action. In a few minutes a

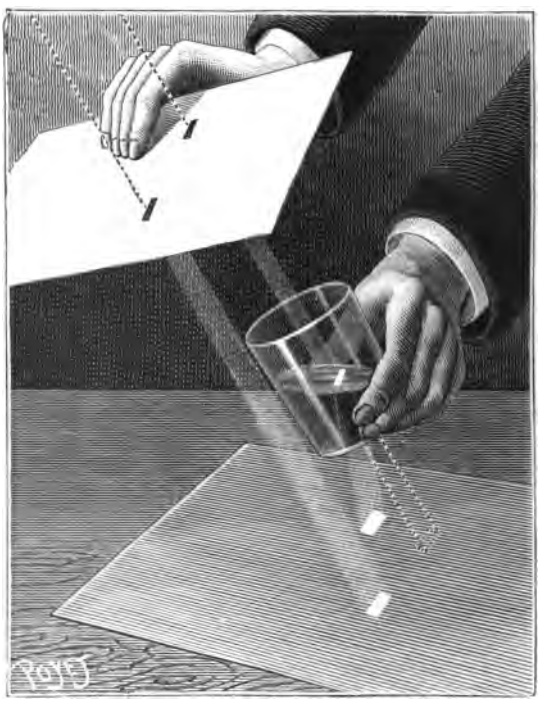


FIG. 86.—WATER PRISM.

message came along. A paper ribbon with mysterious characters spread itself out before us. My friend did not even lift her head to read the ribbon, but continued to write the message. I drew her attention to the fact. She

told me she had been listening while she wrote. I had both listened to the clicking and seen the ribbon, and yet I was totally ignorant of the nature of the message. I went home. A telegraph boy handed me a message. I compared the time and the office, and found them to correspond with that message which I had watched come in. Yet now the telegraph was clear as daylight after passing through my friend's hands. So it is with the light messages: the brain translates them for us. We read them, trust them, and act upon them.

Home Experiments

44. Look at a distant candle-flame, through the fingers nearly closed.

45. (*a*) You have often wanted to borrow my prism to make a spectrum. I will show you how you may make a water prism. Make a slit in a card. Hold a glass of water a little on one side, so that the sunbeam passes through the angle made by the water-surface and the bottom of the glass. The spectrum appears upon a sheet of paper beneath. One slit only is necessary, the other beam is for comparison. See that the tumbler is free from marks and the water is pure. A better way is to cut a slit in the bottom of a bandbox, and turn the bandbox over. You would do well also to make a large hole in the side nearest you, through which you can hold the tumbler.

(*b*) Look at the street lamps to-night through this square of cobalt glass, which I will lend you.

CHAPTER XXIII

FINDING HIDDEN SUNBEAMS—PART I

YOU remember how, in a former story, we traced the carbon di-oxide of the breath in its passage through the air to the leaves of plants, where the sunbeams were waiting to tear the carbon from the fierce grasp of the oxygen, that the plant might be fed. You remember too that directly the carbon and oxygen were free, the oxygen peacefully returned to the atmosphere, where its presence was so much needed. You watched the oxygen bubbles rise through the water, and I daresay you wondered what was to become of the carbon. We left the carbon, if you remember, in the little green cells. Here it met with the liquids which the plant had drawn up through its roots, and here the sunbeams made the plant food by joining the carbon to new substances. Even without the help of the microscope, we can see the neat little packages of food—starch, sugar, and oils—stored up in the plant, and we shall bear in mind the busy sunbeams. One of these new companions of carbon is so important, that I must give you a brief introduction to each other. Ah, where is he? Strangely enough he is in this room very near to you—in fact, in the bowl there. No, there is nothing in that bowl but water, you say. Just so! He is there nevertheless. But like the carbon in the di-

oxide, before the sunbeams interfered, he also is fast to oxygen (we might almost say *married*[1] to oxygen), and the two joined together are *Water*. How shall we separate them, that I may show you *Hydrogen*, for that is his name. If you have a baby at home, you will know how very fond babies are of bright objects. Sometimes baby gets hold of a knife. If your baby ever does so, never try to pull the knife out of his hand, for that is dangerous. What would you do? Yes, offer him something else and he will forget the knife, and very possibly drop it.

I throw a bit of potassium as large as a pea on to the water to tempt the oxygen to leave go. Yes, she eagerly rushes at it as I expected, and in the heat of her excitement she loses hold of half of the hydrogen. The hydrogen thus rudely repulsed seeks another companion. Instantly he draws to himself some oxygen out of the air above the water, with such terrific eagerness that the two burst into flame, and dance round and round the potassium, making it waltz round the bowl with them, as you see. That is the meaning of all this hiss and splutter. The blue flames goes out. A final dart and pop announces that the ceremony is over.

FIG. 87.—POTASSIUM.

Meanwhile what has become of the oxygen and its new companion, the potassium, along with the rest of the hydrogen. They formed a new substance (potash) very like soda, which immediately dissolved in the water. Put your finger into the bowl and feel how soapy the water is, Minnie. But, I forgot, you wanted to see Hydrogen?

[1] Faraday, if I remember rightly, uses this term.

Unfortunately, he is invisible except as a blue flame. If I turn this gas-tap you will see nothing come out of the pipe. Quite right, Nellie. You can *smell* the gas, though. But hydrogen, which is a near relation to coal-gas, has no smell, yet I think we shall find some way of distinguishing him. I will make the experiment again rather differently, this time taking care that the hydrogen does not get married, by keeping him from contact with the air. I fold the potassium up in this piece of wire gauze and fix it to a spoon, so that we can hold it under water all the time. Freddy, you are not afraid to hold it, are you? Its behaviour will be much more gentle now. I shall hold this tube over. Watch! I plunge the tube in water. When it is *quite* full I turn it upside down *in* the water, and carefully raise it, but *not* above the surface. See how quickly it fills! It is full! I stop up the opening with my finger, and withdraw the tube from the water. Alfred, strike a match. Thank you. See, I still hold the tube mouth downwards, and now withdrawing my finger I apply the light. Did you hear the "pop" as if from a penny gun. That means that the hydrogen is mixed with air, hence the little explosion. We will catch some more. Freddy shall lower the black blind before we present the light, when next the tube is full. Now, Freddy! See, this time the blue flame burns steadily at the mouth of the tube, and though I push a match or taper inside the tube the hydrogen refuses to burn except at the mouth. Now we will catch a glassful of it in the same way. Can you hold it, Mary? Don't be frightened! Please bring me another clean tumbler or a

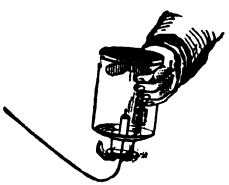


FIG. 88.—The taper will not burn inside. But the neck of the bottle is surrounded by a blue flame.

glass jar, Ada. This is a bottle, but it will do. Are you sure there is nothing in it? "It is full of air." Very good. I will try with a match if it be quite free from hydrogen. You are satisfied? I turn it upside down and place a cold saucer over it. Now I gently bring this inverted bottle of hydrogen near. Then, withdrawing my hand from beneath, I lower it to the horizontal position, thus—

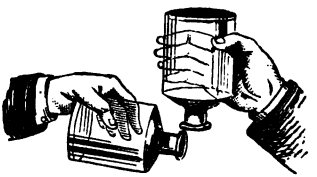


FIG. 89.—POURING HYDROGEN UPWARDS.

I apply a light to the contents of each bottle. We recognise at once our hydrogen burning in the upper one. How so? We have poured the hydrogen *upwards* in this curious way —the opposite way to which we pour water. This shows us how *very light* hydrogen must be. But our experiment shows us something more. Look at the saucer, Florrie. You tell me, it is steamed. See the drops of water trickling down the sides. Who has seen the same appearance on the inner side of the kettle-lid? Look at the sides of the bottle too. "They are wet." How is it?

Again the hydrogen has caught hold of the passing oxygen about the mouth. That blue flame signalled the marriage of hydrogen with oxygen. This water is the result. *Water is always formed when hydrogen burns in the air.* This hydrogen is *the only thing in Nature* which produces water, and *water alone*, by its burning.

Home Experiments

46. This week you will practise those experiments which we made in our last. Make the thaumatrope.

47. Throw images on the blind spot.

48. Throw shadows on the retina with pill-box camera.

49. See different views of the same object by closing the eyes, first one and then the other.

50. Try to see a near object (veil, net, gauze) and a distant one distinctly at the same time.

51. Whirl round a glowing stick or rope.

52. See double. Fix up a penholder or pencil at some distance, say the other end of the table. Stand opposite to it. Now hold up another in the hand *nearly* in the same straight line. Fix your eye first upon the near one, then turning to the distant one, the first will be seen double; when the first one "comes right," the second one is seen double. (Once I was at a crowded meeting, and could only see the speaker through a crevice about a yard in front of me. First I saw *two slits*, and when I had "cured" that, I saw *two figures of the speaker* side by side.) Try this also, if you like.

53. The test for colour-blindness, which you have tried before, belongs also to this list, viz. looking at a coloured object till those nerves are tired, and only the other sets are able to work. (Those who do not see the image formed by the other colour-rays are said to be colour-blind, and there are many positions in which they could not be employed, *e.g.* we should not think of making such a boy a signalman or a draper when he grew up.) Think on these experiments as you make them, and be sure you understand the cause of each.

CHAPTER XXIV

FINDING HIDDEN SUNBEAMS—PART II

I NOTICED that several of you looked very much astonished when I spoke of gas in the fire. Let me show you that it does not necessarily require a large gas-works to produce the gas which we burn in our houses in the evening.

I fill the bowl of this tobacco-pipe with bits of coal the size of peas. Now I close up the opening with pipeclay or common clay—either will do. Then I fix the bowl in the bars of the grate, so. Or if you prefer to hold it over the spirit-lamp, you may. Yes? Come then, Albert, if you wish, and hold it for us. This is exactly how gas is made at the gas-works, only that there are immense ovens to roast the coal in, and large cylinders in which to store up the gas till it is required.

Now you see the gas coming off at the end of the pipe. We will light it. This is a new way of smoking a pipe! The oil of the plants has been made very hot, and has risen up the pipe-stem as a gas. This light which we enjoy now, is the work of those busy plants, who, with the help of the busier sunbeams, filled their store-houses with all manner of good things done up into neat little packages for the use of themselves and their families. No one saw them, no one admired them, except possibly a few crickets and

grasshoppers, a large kind of spider, or some huge member of the frog family, for it was long before any children lived on this earth, ages and ages ago.

But it is not necessary that plants should be buried and crushed in the earth in order to produce gas. We can and

FIG. 90.—GAS FROM PAPER.

do get gas from wood, and even from paper. If you think for a moment you will see that this is so, for do we not use both to kindle the coal? That shows that the gas has a harder struggle to get out of coal. I put a bit of wood in this short piece of narrow glass tubing (after having closed up the end of the tube by holding it in the gas-flame). The wood is simply a match with the head broken off. Now I heat the ube. See, the gas is coming off and also a brown liquid

(tar). I light the gas at the open end of the tube. What do you think about it?

Again, paper is made from ——? "Rags." Rags are made originally from plants, *e.g.* cotton and flax. I take this paper and turn it round my finger, making it into a little cone. I set a light to the wide end. The gas collects in the narrow end. I make a hole and light the gas here (Fig. 90).

I scarcely think the flame from our tobacco-pipe is steady enough to ask you to look at. I will light this jet instead; the burner will control the flame. First, then, let us consider flame to be a bubble of light. The flame of this spirit-lamp, or even that issuing from our tobacco-pipe, will perhaps help you to realise this better. I press a piece of paper down upon this flame, however, and you see a blackened ring where the flame has touched it. If you try this at home, you probably won't succeed at first; it requires a little practice to keep the paper from catching fire. If you damp the paper you will do better. Now let us find out what is inside the bubble. This piece of glass tubing was bent in the gas-flame, but I don't think you can manage that yet. Very curious it is to see the gas burning at the end! (Fig. 91). I shall take this other pipe and place the bowl (which is not too large, I think) in that dark part of the flame, and now I light the mouth-end of the pipe. I will break off the bowl and try the same experiment with the gas-flame. So now we see what is inside the bubble. What is inside the bubble, Herbert? "Air." No, not air; we cannot burn air so. Yes, Frank, it

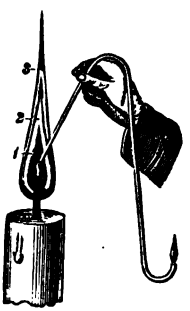


FIG. 91.—The candle is a miniature gas-works!

is gas. I see you are puzzled, Herbert, because we use the term "gas." You thought that the gas that we usually light, which you have seen, is made from coal—was the only gas in the world! "Yes, I thought so." But we have seen that in the flame of the lamp and the candle, the taper and the match, we have the burning of a gas very similar to the coal-gas, and we shall see further how like they are. Now we have found out that the gas bubble, so to speak, burns only on the outside, and inside is full of *unburnt* gas.

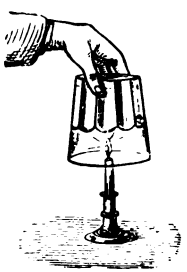


FIG. 92.—WATER!

I hold this clear bright tumbler over the candle-flame (Fig. 92). Watch carefully. What do you see? The "steaming," as you call it. We call those little drops of water "dew"—but no matter. Ah! so many hands are raised now. "It must be hydrogen burning." Yes, Freddy, you remember your friend hydrogen uniting with the oxygen to form ——? Where does the oxygen come from? Yes, from the air on the outside of the bubble. I might repeat the experiment with the gas-flame with like result—while you all know how "steamed" the lamp chimney is for the first few minutes after the lamp has been lighted. Now your lamp will have a new meaning for you. You remember too, I daresay, that I once turned up the flame of the lamp and smoked the glass, and that we afterwards examined the black flakes on a sheet of paper. Do you remember what it is called? And what it is used for? Now hold a saucer over this candle in the bright part of the flame. Here too are fine particles of soot or carbon. Is it not strange that these black smuts should come out of the *brightest* part of the flame? Did we not see how bright the black cinders became

in the very heart of the fire? See, I will push one of those whitest cinders out of the fire; don't lose sight of it. See, it turns yellow, then orange, then red, dull red, and now it is almost black, now it is very black. I should offend you if I asked you if you could sharpen a slate-pencil? Yes, you all can do that, and some of you can do it very nicely too! In sharpening this black-lead pencil, I cut away first the wood and then a portion of the lead, to make a point, do I not, whereas you rub your slate-pencil away till you get a point? What is left behind? Right, little bits of pencil, fine as dust. In sharpening a knife, little bits of the steel blade are rubbed off in a similar manner. See, I draw the knife across this stone. Now feel the blade, Harry, Tom, Jim! It is hot, is it? Are you surprised? Watch now, perhaps I shall succeed in making the very, very tiny bits that come away so hot that they will take fire. See the sparks fly! Those sparks are bits of steel or iron burning in the oxygen of our air-ocean. They become instantly white-hot, and directly become a new substance—iron-oxide or "rust." The black specks of carbon on the saucer, were white-hot too, as they danced about in the flame before we caught them here.

Now I will borrow your round ruler, Mary. I coil three or four turns of wire round it. Now I push it off the ruler and bend the wire round like the letter *f*. See, I have made a sort of cage with a long handle. The little cage will hold the bit of candle, so. Now I lower the lighted candle into this pickle-bottle (Fig. 93). You see at once the dew on the glass, but how is it that the candle does not burn? Mary, was the bottle quite clean? Yes, you washed it yourself and let the cold water run into it from the tap. There! the candle has gone out; we must light it again. Now we lower it once more into the bottle. What! out

already? I pour some clear lime-water into the bottle and shake it up. Now, boys, what is that? "Chalk in the water." Yes. What makes chalk with lime-water? "Carbon di-oxide." Yes. Where has it come from? You are right in supposing that those bits of carbon get burnt up at last, and the result is carbon di-oxide.

Now let us try to gather up what we have learned. First, what have we got out of these flames? Perhaps it will help you if I draw a picture of the flame on the board while you follow me on your slates (see Fig. 91).

How did the gas get into the wick, Edith asks. Ah! we must begin at the very beginning. You strike a match and hold it an instant over the wick. If the candle has not been lighted before, you must wait while the wax or tallow melts and then slowly rises in the wick, how—I will tell you more fully another day. See, I put the end of a towel in this bowl of water. Many a little girl has forgotten to hang up the towel after washing her hands; by and by her mother comes that way and finds a pool of water on the floor. How has it got there, she wonders! See how the water is spreading over this towel as though every fibre were a little tube, which it really is. In this way, the oil rises up the wick and, near the hot match, soon turns to gas which we can light.

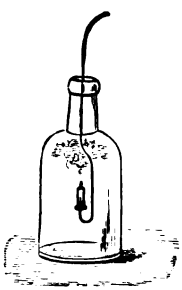


FIG. 93.—CANDLE BURNING IN BOTTLE.

(1) We saw that the *inside* of the flame-bubble was filled with *unburnt gas* pouring out of the countless pipes which form the wick (Fig. 91, 1). The bubble is covered with two shells or "mantles," as they are called.

(2) The inside one is the bright part that gives out light

(Fig. 91, 2). It is the ball-room of the now white-hot "smuts."

(3) The outside one is not so good to see (Fig. 93, 3), but with care you may trace it all the way round. This mantle is lined with bright blue. We catch sight of the pretty lining if we look below the wick. Do you see it? The outside of the mantle is pale blue, not easily noticed. I strike this match and let the knob grow red before I blow the flame out. That will do; by its help we can trace the faint outer mantle, for the match held near will colour it for us. Do you see it? Here the smuts step from ball-room to the *battle-ground*! Instantly each atom of carbon is violently seized upon by two atoms of oxygen, always on the alert, in air-ocean which surrounds the flame. How fiercely the war wages this flame plainly tells, as I hold my hand above it. That heat is due entirely to the clashing of those atoms together. In the end the oxygen is victorious, as you know. The heat of the struggle has raised the white-hot carbon to the state of gas, in which state it is borne away by the oxygen. Our carbon di-oxide is nothing more than a procession formed by these oxygen atoms hurrying away with their captives!

But we have yet to account for the water which appeared in drops of dew inside the tumbler and the pickle-bottle. That, you told me, was hydrogen and oxygen. We know that there is an ocean of oxygen round the bubble and that some will force its way inside. But where did the hydrogen come from? Shall I tell you? The gas which came up through those wick-tubes was nothing but carbon and hydrogen. We have followed the carbon on its travels from the moment the hydrogen let go of it. Why did the hydrogen let go the carbon?

You remember how, in our last experiment, hydrogen

pulled the oxygen out of the air above the water the moment he was free? This is what he almost always does if any free oxygen is about. But was there no battle fought, you ask? Yes, indeed—so much so that the carbon became very red with the strife, and finally white-hot, giving out that dazzling brightness, which you can't look closely at without injuring your eyes. So that the *light* as well as the heat of that little candle has its story to tell.

What is the difference between the flame of this spirit-lamp and the flame of the candle or gas? Put your hand over the spirit-flame. It is very hot, you say. Do we get a bright light from it? "No!" There are no smuts dancing about white-hot in this flame. Try it. Press the saucer down where you will, you can get no soot out of it; and because it has not had to heat little bits of soot, it is much hotter than the gas-flame.

Home Experiments

54. Make coal-gas in a tobacco-pipe inserting the bowl in the bars of the grate.

55. Press damp paper down on a gas-flame and obtain a charred ring (*section of bubble*).

56. Sharpen an old knife, and notice the fine bits of steel take fire as they burn in the oxygen of the air.

CHAPTER XXV

TRAPS THAT CAUGHT SUNBEAMS AGES AGO

I AM sure you will all remember what you learned in the Infants' School about coal. How that millions and millions of years ago plants grew upon this earth as the buttercups and dandelions grow in the meadows to-day, though perhaps not of quite the same kind as those growing now in our gardens and fields.

Here is a picture of a Coal Forest. Perhaps you don't recognise anything here. See, those great trees with the diamond-marked trunks, with the dark leaves spread out at the top of the picture—their descendants, *i.e.* their relations, who are living now are tiny club-mosses. Bending across the water at the bottom of the picture are some trees uncommonly like the "horsetails" that you gather on the sedgy bank. You will readily believe these trees to be their stalwart ancestors. On the left bank, too, you will recognise a fern, though there were also large tree-ferns at that period. Do you see those trees with heads like brushes? Observe their curious trunks which appear to have been stamped all over with a seal. These are scars left behind by the leaves as they dropped off.

Suppose that the coals in the scuttle should one day say to their dwarf descendants, "How is it that you are such

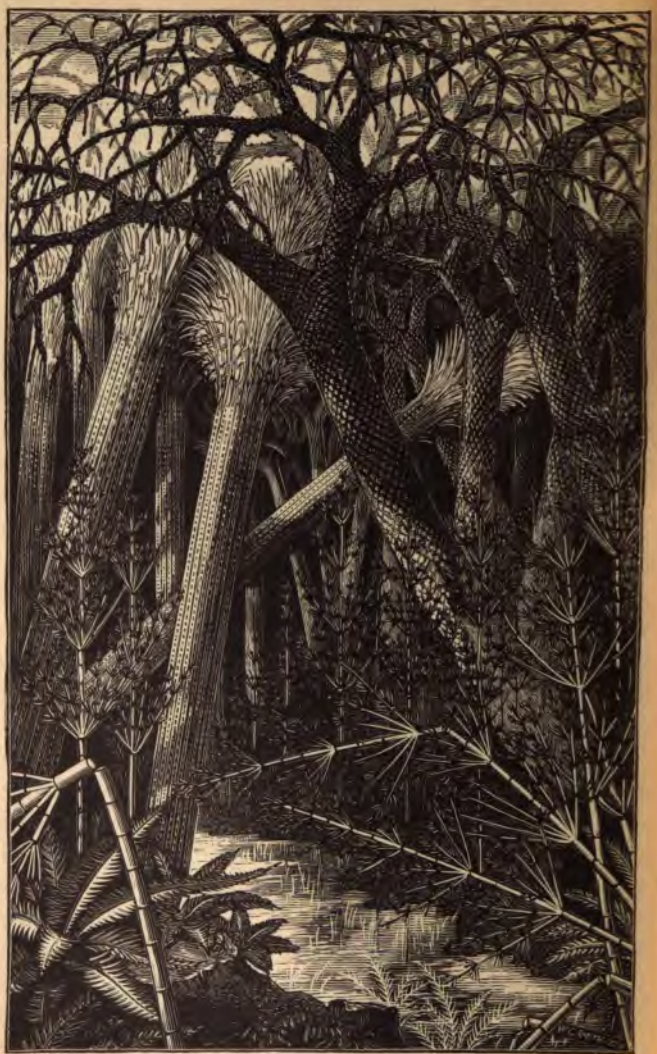


FIG. 94.—A FOREST OF THE COAL PERIOD.

puny miserable creatures?" We might fancy the club-mosses, the ferns, the reeds, and the horsetails answering something like this: "It was all very well, in your day, great-great-great-great-great-great-grandfather, you had all the ground to yourselves, and could grow fine and beautiful, but nobody cares for us. Long, long ago, when our fathers were still giants, flowering plants came upon the earth and pushed us aside. Nobody cared for us then. We are glad now if we may find a home by the river's brink or in some marshy dell, where we can bring up our families in peace."

The trees pictured here grew up into old age and died, fell down and decayed. Their little ones grew up in the old forest home and died likewise on the same spot, and so on for ages, until the ground was covered with old tree-stumps and leaves in a state of decay, through which the young families forced their way upwards. So these trees and plants lived and died, generation after generation.

All this while the land was very slowly and gradually sinking, and after a great many years of sinking the sea flowed over it, bringing with it fine sand and mud, which spread over that old forest and quite buried it. More and more mud and soil were carried there by the water, until a thick bed was formed, and the sea no longer flowed in. Gradually little plants began to peep above the soil, and presently a new forest of tall trees had grown up. The old trees died and fell down where they had lived, and young trees took their places, and so the forest flourished once more, until the ground had sunk so low that the sea flowed in over this second forest and buried it with sand, mud, and clay. In some parts many forests grow up in this way, one above another. It sounds a very strange story, I have no doubt, but let us remember it took a very,

very long time—ages and ages—for these forests to grow up and become buried deep down in the earth. The old plants, with the sunbeams still imprisoned in their leaves, were so pressed together and altered by the layers of heavy mud and sand, which hardened into flat rock and crushed them by their tremendous weight, that at last the forest became one solid mass of black coal, and remained all these millions of years, until brave colliers cut their way through the rock and dug the coal out for our use.

The tar, gas, and oils which the plant stored up in its interior re-appear in the coal of that fire yonder! In its flame you have represented the heat and light of the sunbeams that shone countless ages ago!

Perhaps you may be puzzled at my saying that oil is obtained from plants. Think now of the commonest oil, which you perhaps call "hair oil"; whence is it obtained? Right, Minnie, from the olive. Then there is castor oil, also oil of turpentine, which is obtained from pine-trees. A kind of tar is made out of it. Nuts and seeds, too, contain a very great amount of oil, which, no doubt, you have found out for yourselves ere this. Have you never cracked nuts and wrapped the kernels up in paper and put them in your pocket? If you have, you will have noticed how oily the paper is. Linseed or *linen-seed* is made into tea—you know what for? Perhaps you have seen the house-painter mix his paints. He uses a great deal of linseed oil.

True, these plants did not grow in the Coal Forest, but I hope to show you, possibly next day, that the spores or seed-cases of the club-moss contain a powdery dust, so full of resin that it has often been used in theatres to imitate lightning; it is called by some people "vegetable sulphur."

Now think how the oils would ooze out when the plants became crushed and broken. Look at the fire. Do you see

those black bubbles rising from the unburnt coal! Now they burst. Black smoke rises from them. I hold a match to the "smoke" and find that it lights; it is gas. Those

FIG. 95.—A PRAWN EMPTYING A GLASS OF WATER.

bubbles are of tar, and it is from tar that so many wonderful things are prepared that I should never have finished telling you, so I must only mention a few—benzene; the beautiful dyes—magenta and violet—and from these, green, blue, red, and other colours; perfumes of various kinds.

Then there are what are called essential oils, used for flavouring puddings and blanc-mange, such as oil of bitter almonds; others, such as "essence of Jargonelle pear," are used in making fruit syrups, toffies, and confectionery; there is also a curious substance (*saccharine*) about two hundred times sweeter than sugar; some folks put it in their tea. These are just a few of the many wonderful things obtained in making coal-gas.

Home Experiments

57. Gather horsetails by the brook-side. Examine the outer skin under your microscope. It is sharp and flinty. It appears like an exceedingly fine-cut file. *Nature's file* used to be preferred by cabinetmakers to any other in the days when they took great pains over their work.

If you have any opportunity at any time of gathering the club-moss, bring some to school. I can show many wonderful things about it.

58. Try to burn a candle lowered into a bottle of air.

59. Lay one end of a towel or strip of calico in a bowl of water raised up, *e.g.* on a shelf; let the other end fall into a bowl below. A prawn can be made to empty a glass by this method (Fig. 95).

CHAPTER XXVI

THE IRISCOPE

I DARESAY, when you have been getting your tea at home, with the sunshine streaming in at the window, as it does sometimes—not too often—I always feel sorry when people pull down the blinds; it seems such insult to the kind old Sun, who brings so much pleasure with him—perhaps at tea-time you may have noticed a bright spot on the wall, not quite still, and if you are as anxious to find out how things come about as most children are, you will not rest until you have puzzled out how it came there. I wonder who has seen these patches of light, and found out the cause. If any one has, let him stand. Don't look at one another; if you have seen them, George, stand up. "I *have* seen them, but I don't know how they came there."

Ah! that is better; now two boys have been encouraged to stand by your example, George. Well, Edmund, did you solve the mystery? "Please, teacher, yesterday at dinner I saw a bright circle on the wall, and I thought it must be light reflected from some mirror, but I could not see any about. Then as I looked at it, I was just going to take a drink, and as I touched the glass the image shook, and it moved about when I raised the glass, so I guessed it must be the top of the water which reflected the light. Then I

covered the glass up with my handkerchief and the image went."

Very good, Edmund, you are a little philosopher already! Now, Ernest, what can you tell us? "I saw the same thing, only mine was from my cup of tea; it was nearly oval, not a circle." Very good, Ernest, the same remark applies to

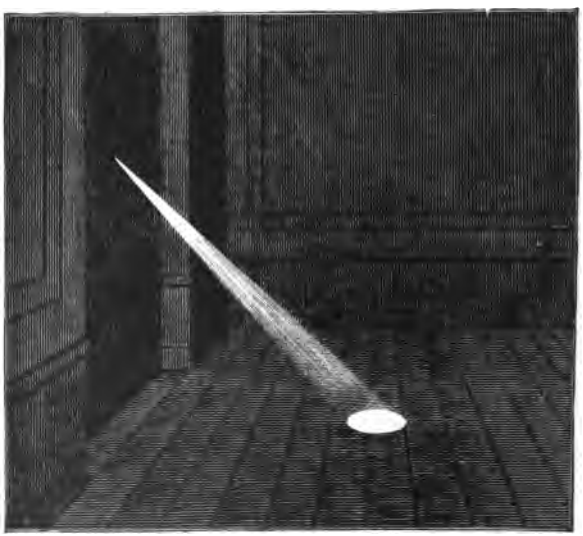


FIG. 96.—A SUNBEAM "AT TEA-TIME" (compare also Figs. 2, 6, and 66).

you. Now we will try to produce the same result for the benefit of the class.

I unscrew and take away the top lens from our sunshine lantern, and make a hole in the blind above the level of the lower one, which shall stand for Edmund's glass of water. You see the image of the water surface on the ceiling?

Ernest, you want to know why Edmund's glass of water produced a circle and your cup of tea an oval? I thought

so. Can you tell me how we shall perform your experiment? When is the sun highest in the sky? At noon, you say. Where is he at tea-time? who can tell? Nearly setting, and you say that he seems to be nearly on a level with our eyes. Now, Ernest, what do you suggest? "Make a hole on a level with the glass basin." I am afraid that would not do altogether, because the sunbeams would come in parallel with those we have just used and strike the water at the same angle. What we want to do, is to bend the sunbeams, making them more horizontal, until they pour into the room, as at sunset (Fig. 96).

We will hold a mirror near the blind in such a position that the reflected beam shall just graze the surface of the liquid. Now, do you see the oval (Fig. 97)? You see that the shape depends on how the beam strikes the surface. Edmund, hold the mirror steadily, exactly in this position that I have it, or the image will tremble. I dip the end of this straw into turpentine and let a single drop fall gently. See how it spreads itself out on the surface of the water. That little drop is trying how much space it can cover surely; is it not wonderful! I believe it will cover the whole surface if we watch patiently. How very, very thin that layer of turpentine must be on top of the water. And just because it is so *exceedingly thin* we have those beautiful colours. Don't forget that, for it is *most important*. Next we shall try a drop of oil. Not only is this true of films of oil and turpentine, but of any

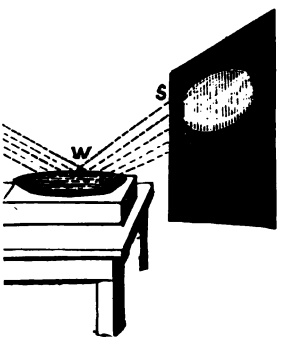


FIG. 97.—OVAL REFLECTION FROM WATER-MIRROR.

substance whatever, solid, liquid, or gaseous. If the film or layer be thin enough, these colours will be formed. In this old iron spoon I placed a bit of lead which George gave me just now. Lead is one of those substances which boys especially delight in, and generally carry about on their person.

Now I hold it over the flame of the spirit-lamp. Harry, throw a beam of light down upon it, and reflect the image to the ceiling. The light must slant very much.

When the lead becomes sufficiently heated it will speedily draw to itself the oxygen passing over its surface. This lead-oxide, as it is called, will appear at first as a very thin film floating on the lead, and will grow gradually into a thicker film as the metal becomes more heated.

Now the colours are coming. We shall lose them when the film becomes of a certain thickness. By its colour workmen can tell how hot the lead is. Now the colours are fast disappearing as the film thickens.

Here is an old carving-knife, which has lost the handle. The blade is very bright, though. I hold it over the flame of the spirit-lamp. As soon as it is *warm* I shall rub it with this paraffine-wax candle and then wipe the wax nearly off again. This makes the colours come more quickly. In a few moments you will see rainbow colours appear in due order. This experiment is similar to the last. The heated iron joins itself to passing oxygen, making a film of iron-oxide. This is a very beautiful experiment.

Now I take this small glass funnel and dip it into a solution of gum. Holding the funnel on its side we can reflect the image of this film on the ceiling as before. The gum is running down. Does it not look strange when reflected? Very soon the film must become too thin to hold together. Which is the thinnest part? "The top."

Right; and as the gum runs down from the top to the bottom the thickness increases. Each colour corresponds to a certain thickness of film.[1] Red at the thickest part, orange next, then yellow, green, blue, indigo, violet, in the order we saw in the spectrum and rainbow. By and by the violet will give way to a black band, then the film will burst.

Once more: we will produce a film of water this time. This pretty experiment you are each going to perform. First watch me; then you will do exactly the same after. I rub this piece of wet soap over the glass, so; then I take this clean soft duster and rub the soap off, so. I daresay you boys will have found suitable tubes lying about in your play-drawers. Albert has brought part of a trumpet, I see.

Now pass the soap quickly round, and while you are polishing your plates I shall distribute to each of you a piece of black tissue-paper.

Now all are ready. Again watch me. I place the black paper under the plate of glass, and holding this piece of rubber tube ($12 \times \frac{3}{4}$ inch) one inch above the *centre* of the plate breathe on the surface. Again we have the rainbow colours. This arrangement is called the Iriscope or Rainbow-viewer.

Home Experiments

60. Hold a dry bright tumbler over a lighted candle and watch the dew-drops trickle down the inside (see Fig. 92).

61. Turn up the lamp-flame *a little*, just so as to smoke the glass. Then turn down the lamp, almost out, and wait some time before removing the chimney, which should be set aside to cool. Examine the fine black carbon.

[1] The corresponding thicknesses in ten-millionths of an inch are—red, 133; orange, 120; yellow, 113½; green, 105½; blue, 98; indigo, 92½; violet, 83½.

CHAPTER XXVII

SOAP-BUBBLES—PART I

In our last story we examined the beautiful images formed by thin films, and we learned that these rainbow tints are produced always, when the film is sufficiently thin. A slice, so to speak, of any substance whatever, solid, liquid, or gaseous, will present these tints. We obtained them from ——? "Turpentine, steel, oil, lead, gum." Very good; and what in the last case—was it not from the moisture of your breath—water vapour? But see, a film of air will do equally well. Press two clean pieces of glass tightly together; you will not be able to squeeze out entirely the layer of air between them, but if you press hard enough you will obtain a very thin film. See, I fasten these two plates together with bulldog clips. Two triangular pieces with a good clip at each corner will give beautiful coloured *circles*, but any pieces pinched together will show colour. I also press as hard as I can in the centre. Do you see the colour-circles? (Fig. 98). You may try it for yourselves after the lesson. Newton pressed together a flat piece of glass and a lens; we can do the same.

It is not necessary even for air to come between. I dare-say some of you have felt the ice crack beneath your feet, or you have unfortunately cracked some glass vessel. Examine

the cracks, if recent. Although they may not have reached the surface, yet you will find a play of colour round them.

There is no need, I am sure, to tell any of the little

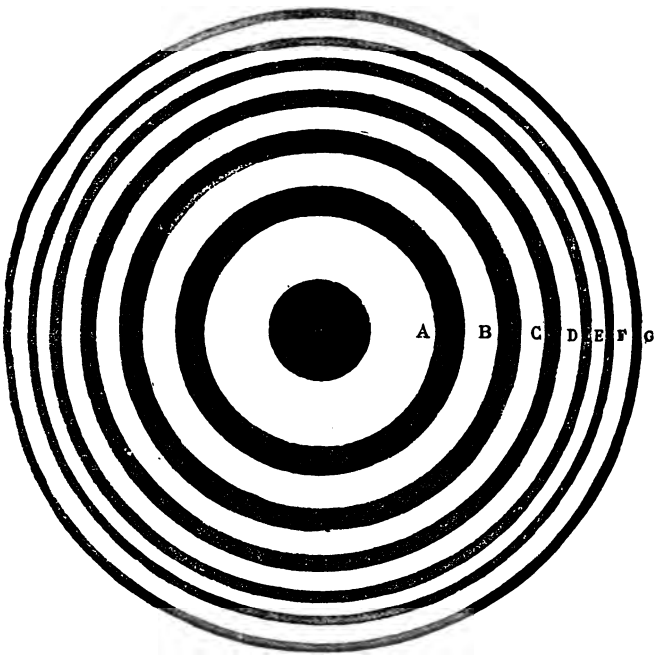


FIG. 98.—NEWTON'S RINGS. Newton found, when a beam of all-coloured light was sent vertically down on to the glasses, that in the centre (where the air was *quite pressed out*) there was a circle of *no-colour* (O), and widening out from this black spot were a series of colour-circles. From O to A, black, blue, white, yellow, red; A to B, violet, blue, green, yellow, red; B to C, purple, blue, green, yellow, red; C to D, green, red; D to E, greenish blue, red; E to F, greenish blue, pale red; F to G, greenish blue, reddish white.

people here how to blow soap-bubbles. I doubt there is not one of you before me who has not tried that experiment many times; but it may be news to you, that some of

the cleverest men that ever lived have spent much time in blowing soap-bubbles and in thinking about them.

The great philosopher, Sir Isaac Newton, and many others since his time, who have continued to think where he left off, have found out some of the most wonderful things that are known about light, from experiments made on thin plates or films, and from the soap-bubble, which is also a thin film like these.

Newton covered his bubble with a glass shade to protect it from draughts, which interfere with the regular order of the colours. I think you will agree that although the bubble may not be so pretty when blown inside a bottle, yet we shall be able to learn something from it, which will make your ordinary efforts still more interesting (Fig. 99).

At first we obtain a small transparent bubble quite colourless, and by blowing more air into the inside we cause the skin or film to stretch out, and in stretching out it becomes thinner and thinner. Not only this, the air outside also presses on the bubble, and the soap-suds naturally run down the sides. All this stretches the skin more tightly, till at last the bubble bursts, because the soap-film becomes too thin to bear the pressing of the air any longer.

First we notice faint tints appear. Then brighter tints appear at the top of the bubble in coloured rings, which slowly spread out and descend, for you remember that each colour corresponds to a certain thickness of the film; and as the bubble is constantly growing thinner at the top, the rings make their way downwards and disappear at the bottom.

Now we will blow another bubble, and notice how the coloured rings follow each other. Here is first red, now blue; again red, blue; again red, blue; now red, green; now red, yellow, green, purple; now red, yellow, green, purple; now red, yellow, green, blue, violet; now red, yellow,

white, blue. Do you see those black spots at the top? That means that the bubble is too thin and is about to burst. Those spots are the last chords of the music of colour!

FIG. 99.

What is the difference between that bubble and one blown without the shade? We will see for ourselves. I will show you how to blow a bubble without any pipe.

Then Edgar will come forward and make one in the same way. I dip my hands in the solution till they are quite covered; at the same time I must be careful to disturb the mixture as little as possible. A considerable quantity of the liquid clings to my hands. I close my left hand, curling round my little finger, nearly closing the hole at the bottom; then I place my right hand above so as to make a trumpet to blow down, and now I think you will see that the bubble reaches down a long way. I should think you could nearly make it touch your toes.

Now, Edgar, you try. It is quite easy. Wonderful, is it not! I shall project Edgar's bubble on to the screen. Do you see the currents rushing up and sweeping round?

But our story is not complete yet. I have told you about the bands, and we have seen these bands mixed up in our last bubble, but to prove conclusively that this mixing of the colours is due to disturbances in the air, I will blow a bubble and put another inside of it. There are several ways of doing this, and some of them are very fussy, but there is no difficulty whatever. I blow a smallish bubble with the pipe, and then removing the pipe from my mouth I close the end with my left thumb. The bubble still hangs on to the pipe. Now I dip a very narrow glass tube, or a bit of pipe-stem, into the suds. I push my little pipe into the side of the bubble, through the skin, and blow very, very gently, simply *breathe* into it. Notice now that as the inner bubble grows, the outer one increases in size also. I withdraw the little pipe. There now, I hold them both for a moment at the pipe end (closing it as before). I particularly want you to notice *the bands on the inner one* and the *mixed* lights of the outer.

Well, George? "Please, why are soap-bubbles round?" Because that shape allows every little bit of the bubble-

skin, so to speak, to draw closer to its neighbours, than any other form does.

"Please, what is that light on the soap bubble?"

When you blow a bubble in a room which is not darkened, you have an image upon its side, the same as that which you will find on your burning-glass. The window, being the brightest object of the room, will be pictured there, and occasionally you may distinguish the curtains and objects near. Out of doors you will see an image of the sun. If you blow a bubble in front of the looking-glass, or other object shading off the direct rays, while the room is brightly illuminated, you will observe on the surface nearest you, an erect image of yourself. At the same time you will see an inverted image of yourself on the inner surface opposite. Try it.

"Can we only blow bubbles with a pipe?" Oh dear, no! Jim, fetch me that bundle of straws out of the cupboard. I'll give you each one. Now slit the straw equally for half an inch or so as I am doing. Now slit each half again and press it back. It looks like a flower—does it? "Yes, it is like a periwinkle." You can blow big bubbles with that (Fig. 100).

To-morrow is a holiday, as you are all aware. Many of you are going away—I hope you will enjoy yourselves! Some of you are going nowhere, I am told, and I have been asked by certain boys, and some girls too, if they may come down to school and make a sunshine lantern and other things they want. I have decided to allow those who have nowhere better to go, to come and play in the school-yard in the afternoon, and those who prefer to work may come into school. I shall be here. In the morning we—that is, a few of us—will make a sundial in a quiet corner of the school-yard. It will take us all day to mark it correctly.

I understand also that Freddy Wilson has some pond specimens he wishes to show you. He has asked me for the use of the solar microscope, which I most willingly lend for the occasion.

FIG. 100.

Harry Smith, carrying out a hint that I gave him, has succeeded in making some wonderful lenses from Canada balsam, and has fixed one in his pill-box camera. Perhaps Harry will bring his Canada balsam to school, and show

you how to make microscopes out of pill-boxes. "Yes, teacher."

I don't know whether I ought to tell you that Harry has been making attempts to take photographs with his new lens and camera. So far he has not been successful. The prepared paper which we used in the class, Harry, for the maiden-hair fern was what photographers use to *print* the photographs on after the photo. has been taken on glass.

Would you like to see a photograph taken from the beginning, Harry? Ernest Leigh is not at school to-day? "No; they are going to Australia." Yes, he told me that this was his last week with us. Would you like to have a portrait of him? If so, perhaps you might bring him to-morrow to the playground, and we will surprise him—that is, if you can keep the secret until the photo. is finished. I will "take" him when he least suspects it.

Harry, you shall have a seat inside the camera and watch. "Inside the camera?" Yes, the class-room will be my camera. I shall fix the lens in the black blind, and receive the image on the screen as usual. I shall have a piece of orange-coloured tissue-paper covered over the pane above the one I find most convenient to use for the photo. When the image is sharply defined on the screen, I shall wind up the lens opposite to the orange-coloured paper, while I put the prepared plate in place of the screen. Then I shall wind down my lens to the former place. When the photograph is taken I shall wind up the lens again in front of the tissue-paper to finish the picture by the orange-coloured light, which does not spoil it.

"Can I come in too?" I think you would be tired, for you would have to sit still a long time, as I could not have the door opened. However, I leave that with you. After that, I shall make a stereoscope out of this chalk-box or a

cigar-box. That will take about ten minutes. I shall want some little nails, as for picture-frames, tacks, a hammer, a rule, and a penny looking-glass.

Then if there be any time left I will show those of you who bring two tin canisters (such as hold 1 lb. of coffee) how to make a kaleidoscope. You will want two circles of glass as large as the end of your canister (or pieces of glass from which they can be cut), and some little bits of coloured glass. That is all. I have some black varnish at school.

Home Experiment

62. (*a*) Repeat as many as you can of the thin plate experiments, pouring oil, turpentine, gum, etc., on water, and heating steel, lead, etc. Press glass. Find others.

(*b*) I am giving to each of you a square inch of a very interesting substance called mica or talc. With a penknife, or even the thumb nail, you may separate a very thin slice ; and yet this thin slice may be split again and again many times. At each cleavage, you will observe the succession of colours with the varying thinness, as in the soap-bubble.

CHAPTER XXVIII

SOAP-BUBBLES—PART II

To-day I am prepared to meet your request for another talk about the soap-bubbles and films. I do so with the greatest pleasure, not because I can say very much more with respect to the cause of colour than you already know, but because of the interest you have plainly shown both in your school and home experiments. When you have succeeded you have been overjoyed: when you have failed you have sought me that you might know "*why*?" To-day, therefore, I shall try more particularly to explain the practical part, so that you may be encouraged in making your experiments. Experiments are always interesting, no less so when we fail than when we succeed. You don't agree to that, I see! You like always to succeed! It is certainly more pleasing to succeed, and yet from *failures thought out* has sprung the best part of our knowledge. I know of no experiments so fascinating to children as soap-bubbles, and, as I have said before, not merely to children, but to some of our cleverest men. Do you not already feel a deeper interest in blowing bubbles than you enjoyed before these lessons began? Yes! you do, undoubtedly. First, then, let me see how you make your soap-suds. You have a suspicion that my mixture is slightly different from yours, because the bubbles last longer, and you are

quite right. I will tell you all about it. Mine is rather more troublesome to make. First, I will give you a simple way to make a very good mixture for ordinary bubbles.

The water should be distilled; that you can't do. The next best is *clean* rain-water, which you all can get. Wait until the rain has come down for a short time. Rain washes the air and makes it clean and pure, bringing down all the smuts and dust. We must wait a while till we are sure that most of these have been washed down. Then you may place a large shallow dish out of doors to fill. Afterwards ask some one carefully to pour the clean water into a bottle or jar. Take care that no smuts go in, or you must filter it through folded blotting-paper or a clean handkerchief. Use either Castille soap and Price's glycerine [1] (common glycerine will not do), or use Pears's soap. Charlie wants to know why we must be so particular about the water. I am glad that he has asked me. First, tell me—do you ever see the sunshine reflected from a dirty window? Remember, too, how very thin the skin of the bubble is, and how rapidly the water evaporates or "dries up." The impurities dissolved in the water remain behind on the bubble-skin.

This ring, 2 inches in diameter, is made of finest copper wire; it should be neatly soldered at the joint, but as you can't do that, I have selected the thinnest wire so that you can bend it very *evenly* with the fingers or *pliers*, and twist the wires together a few times. You see the end of the handle is left straight to push into a cork, which fits into a bottle of water as a firm support. A large curtain-

[1] Half an ounce of soap to a pint of water, filter through blotting-paper, add half its bulk of glycerine.

A little friend of mine makes excellent bubbles with a solution of soft soap, to which a spoonful of treacle is added.

ring with handle of fine copper wire will do, if you cannot manage the joint neatly. Here is a thicker wire ring, 3 inches in diameter, which I have soldered. I don't think you can easily find the joint, for I filed it quite smooth (Fig. 101). Dip the ring in a saucer of soap-solution. A thin skin sticks to it, stretched across like the head of a drum or tambourine. You can turn it round by the hand. Freddy, lower the blind, and place the condenser in front! I rear up this hand-mirror so as to reflect the light on the film. Now you

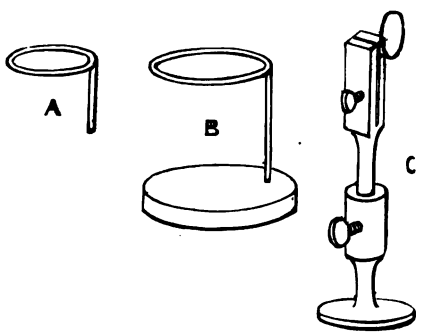


FIG. 101.—RINGS OF WIRE NEATLY SOLDERED. A, 3 inches. B, 4 inches, fixed in cork or disc of wood. C shows the same in Bunsen holder; *the stem is lowermost* to preserve the film.

see the bands of colour! I will reflect its image to the screen (Fig. 102). You would be surprised how tough the film is! It behaves just like a piece of stretched indiarubber; yet it is so light and fairy-like in colour as almost to suggest the wing of a May-fly. I blow strongly down upon it; it stretches out like a purse,—have you ever seen water hanging from the tap in this form? Just before it dropped, it was preparing to become a tiny globe of water (Fig. 103). We could almost fancy, water had a skin like our soap-bubble, for it behaves in a similar way; but if that be so, the skin or surface of water can't be so tough as

the skin of our bubble. The skin of pure water grows thin too fast to make bubbles of—it stretches too much. If we could make a pure water bubble it would grow large so rapidly that it would burst in an instant! You see directly that I leave off blowing, the film springs back to its original form. Do you know of anything else which springs back in this way? "A piece of elastic." Yes, there are other *elastic* things in the world, besides what you call "elastic." This film, for instance, is elastic; by that we mean that it springs back into its original form when you let go, after pulling or pushing it out of shape.

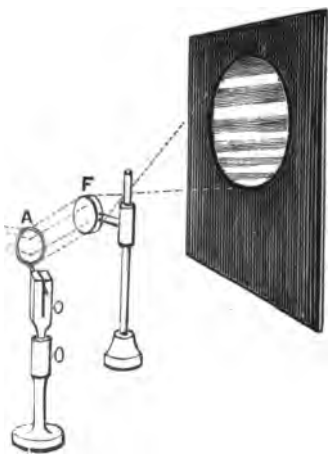


FIG. 102.

I take this little circle of paper and draw a needle and knotted thread through the centre. I dip the ring again and obtain a new film. Now holding the needle in my hand, I dip the paper and end of the silk into the mixture. Holding the paper disc by the thread I drop it on the middle of the film, to which it sticks, and now I can gently and slowly raise the same until it makes a *lamp-shade or a dunce's*

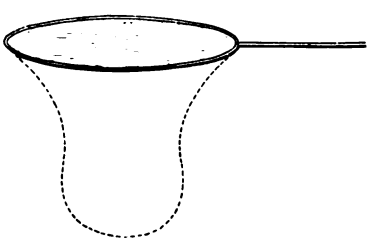


FIG. 103.

cap. Now, taking another film (it is better to withdraw the cork, together with the ring, when dipping, than to fix the wire in the cork each time), with a tiny ring and thread, or paper and thread, I draw the film downwards into the shape of a funnel or a fishing-net. You now see how elastic the soap-film is.

I tie a silk thread loosely across the ring from side to side and dip as before. See how easily the thread moves about in the ring (Fig. 104*a*). Now I break the film on one side of the thread with this spill of blotting-paper; the remaining film at once pulls the thread quite tight in a circular form (Fig. 104*b*). Now, Mary, thread me the needle again, double the silk, put a knot about an inch from the end, and an inch above that make another knot. I will now leave only the part between the knots double and cut away the extra thread at the ends. I tie this thread on to the ring (Fig. 105*a*). The threads are quite loose, you see. I touch them with this spill of blotting-paper or a needle dipped in the mixture. I can move them about. Holding the needle for a moment in the flame of a candle, I now touch the film between the threads, with the result which you see! Inside is an empty space, and the film is pulling at the thread equally on all sides, *making the gap as large as possible.* The largest space our loop can enclose is a circle (Fig. 105*b*).

Look now, I will dip the ring again, and this time I will have to pull too—we will see which can pull hardest! I will tie the string to this pointer. Now the string shall lie loosely across, and I will break the film on one side as before. Now I shall be able to pull back. Yes, I've won! Oh, look! while I'm talking, the film has pulled the thread back again. I pull it again, and stretch it once more over the ring. Now it covers the ring once more. Just look!

If I don't keep on pulling against it all the time, it has its own way (Fig. 106)!

I now want to show you how like an indiarubber ball a soap-bubble is. I should like to show you how it floats and

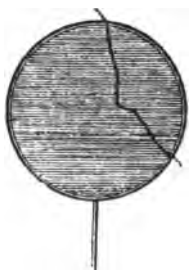


FIG. 104 (*a*).

(*b*).

bounces, but I must not. "Why?" Because I do not wish to make any experiments that you may not try for yourselves, however interesting they may be to watch.

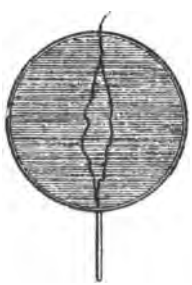
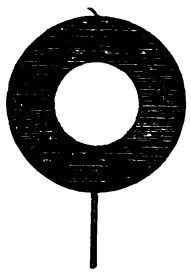


FIG. 105 (*a*).



(*b*).

These would be dangerous in your hands, and therefore I shall not attempt them.

Perhaps some of you may have possessed an indiarubber all with a hole in it. Babies' balls are made this way and

those that squeak. You are right, the indiarubber men and animals are made so. Here is such a ball. I can squeeze it up in my hand, and yet, when I let go, it fills with air and becomes quite round again. I can force the air out again in a stream upon your face, Fanny. Do you feel it?

The air inside the ball is struggling to get out—trying to force its way through the indiarubber in every part. The air *outside* the ball is trying also to force its way inside through the indiarubber.

Now I will blow a large bubble with my pipe. Directly I stop blowing, the air outside gains the victory and presses too hard on the bubble, which is now rapidly growing less. But where is the inside air going to? It is being pushed out. I will blow the bubble up again. Now I hold the mouthpiece to this candle-flame. See how it is blown aside, and now the candle actually goes out—that tells a tale, does it not? Let us try now to find out whether the air in a little bubble or that in a big bubble is being pressed on most by the air outside. I shall blow a little bubble and a big bubble, and then connect them by the tube. If they are both being pressed on equally they will remain unchanged. If one is being pressed on more than the other, that one will have to "give in." You see these two little glass tubes (clay pipe-stem will do)—one has a bit of indiarubber at the end; when the bubbles are blown I shall connect the tubes by it.

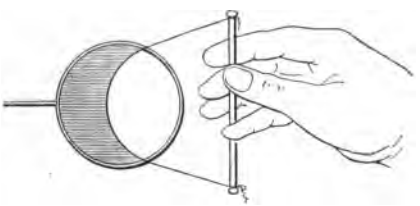


FIG. 106.

Now, watch! I blow a large bubble and close the tube with my left thumb so, while I blow the other smaller one half the size. The small one is in my right hand. I

FIG. 107.—A SILHOUETTE ARTIST.

connect them by pushing this end into the indiarubber. One has grown much larger. Which? One is fast "giving in," or rather "breathing out"—which? Now you can tell me whether the air inside a large bubble or that inside a small one is more pressed. You are right in saying "the

air inside the smaller one." The air made the most desperate effort to get out of that one.

You will be sorry to hear that our time is up. I intended to show you a very pretty experiment with a soap-film and a few with soap-bubbles. Perhaps I may do so on another occasion.

Home Experiment

63. Before photographs were to be had, people were very glad to possess black pictures of their friends. Perhaps your parents may have some of these pictures by them, even now. I have thought of an easy way for you to make such a portrait. Take your little brother or sister near the blind and place the lamp on the table *near*, raising it up with books till on a level with the head. Get a clear, sharp shadow on the blind, then take a sheet of this slate-paper and pin it to the blind, with the black side against the blind and the white side showing into the room. When you have the shadow on the middle of the paper small, sharp, and clear, go and mark it out in pencil, then cut it out, turn it over, and paste the black picture on a sheet of white paper.

CHAPTER XXIX

SOAP-BUBBLES—PART III

ARE you sure you are not tired of soap-bubbles, children? "No, no! We never tire of soap-bubbles." Well, we will go on. This pipe has lain soaking in the mixture for some time, it ought to be in good working order! When I dip the bowl of the pipe in the suds, a film stretches across the opening, just as it did on the ring. Now we saw that blowing on that film drew it out to a purse-like shape, just as the water-drops formed before they fell. Then the water-drops became ——? "Round." Now I give the bubble a shake and it falls from the pipe, just as the drop falls from the water tap—except that the soapy skin is more "sticky" and clings to the tube longer.

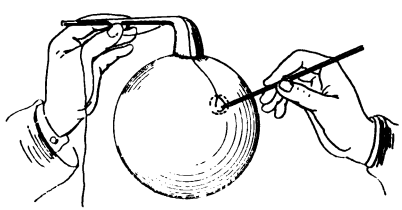


FIG. 108.

Now I am going to make a bubble with a hole in it (Fig. 108). I hang this looped silk over the pipe when I dip it. I blow the bubble as usual; the silk clings to it. Then I touch inside the loop with a spill of blotting-

paper. Now I have made a hole as wide as the end of my pencil. See how rapidly the bubble is going down. I hold it against your face, Charlie; do you feel the puffs of air on your cheek? Now I will make the same experiment again. This time I shall try my best to keep the bubble large notwithstanding the hole. There, I can only do so by blowing very, very hard; it is quite a struggle!

I propose to show you that the rings are not absolutely necessary, though they are helpful. I take a small saucer and dip it in solution, then drain it. Now I blow a bubble on that. I take this little tumbler and dip it in the same way and blow a bubble on that. I take also this tray, and smearing it well over with mixture, blow a very large bubble by inserting my narrow pipe under the liquid that still remains on its surface. I put some liquid on and invite Tom, Albert, Edgar, Minnie, and Annie to blow into it at the same time. Now what have we here? A large group of bubbles. But they are not round, you say! Count how many sides each has. "Six." They are like rounded cubes, you say. Why is this? It is because the bubbles press on each other.

I wish now to show you how real and substantial a thing a film is. Fixing the film vertically in the cork, I place behind it a lighted candle. Blowing strongly against the film does not put out the candle; see what a firm shield it is! At last it has broken—and the candle goes out immediately.

Here is a pendulum which I have fixed up in such a way that it will not twist. I paint a film on the ring and set it swinging (Fig. 109). Harold says he is afraid he can't make the pendulum. What shall I do, children?—for I am most anxious that you should be able to carry out all the experiments we make here. I shall place it aside for

your inspection, for the present, and make a *very simple form* which will answer just as well. Here is a ring made by first twisting the wire into the letter O, then spreading out the ends at an angle like the letter V. The extreme ends are then turned into tiny loops. I tie silk strings to these loops and hang up each to a tack in the top cross-bar of our easel. Our pendulum mounted in this way will not turn round, but will move backwards and forwards as a pendulum ought to do. I can either paint a film over it, or dip it by holding up the saucer, so. But before I do either, I want you to count one, two, three, etc., to its swinging. Now. You see that it keeps perfect time in its movements, from the moment I set it going until it stops. I set it off again. It *seems* to go faster at first, but that is because it *swings out further* each time. Now I put the film on. Count now! What is the difference? It moves much more slowly over the ground; that is to say, it does not swing out so far at each tick; but notice that *the ticks follow each other in the same time* as before we put the film on. Yes, our pendulum has to push the air in front of it as it moves along. Very little air was in front of the wire rim, but now it has to push all the air that is in front of the circular disc and sweep it along with it. That is hard work. I will help it by blowing against the disc.

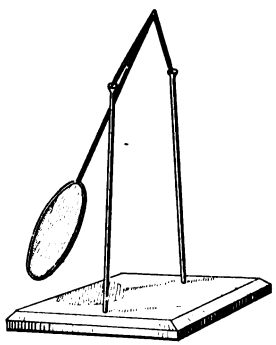


FIG. 109.

Here I have made a *windmill* of soap-films on the same plan as those of coloured paper which are sold in the street. First I pushed a long wire straight through a tiny cork,

then pushed another *exactly* across making the letter X. Then I turned the ends into circles. I pushed a pin through the cork into this stick, which serves as a handle. The cork must turn very freely on the pin. I hold the head of it on the table to show you that the discs all lie flat down. See, they are all on the same level and press against the table everywhere. Now that I have explained so fully you will allow me to mount mine in this stand, so that my hands may be freed (Fig. 110). The sails will bear blowing against if you do it carefully; but by and by the films break one by one. You see how very strong and elastic these films are.

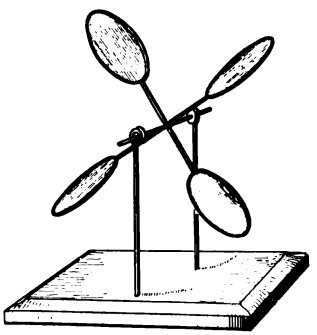


FIG. 110.

This next experiment will have a particular charm for you, I think. I blow a bubble on a ring, so. Now by sucking air out of it we have, as you see, a *double convex lens* (Fig. 111).

Plateau, of whom I shall speak next day, formed in a similar way a double convex lens of liquid, which he delights to tell us is superior to a glass lens, inasmuch as he can (as we have just seen) vary its roundness, and therefore its magnifying power. But the mind of Plateau did not stop here. If convex faces could be formed, then why not flat, and concave? Substituting for the wire ring, a hollow cylinder—a form which we might represent by your pill-

FIG. 111.

box without ends—a mere hoop or band of iron, he obtained a figure with plane faces—a sort of drum, filled not with *air*, but liquid. On applying a syringe or pipe to this, the ends became drawn in, forming a double concave lens as he desired.

He was not content yet! I daresay you are able to guess the next step! He hung up his two lenses on a stout wire, taking care that their centres were exactly at the same height. He then found, by moving them nearer together or further apart, that when the distance between

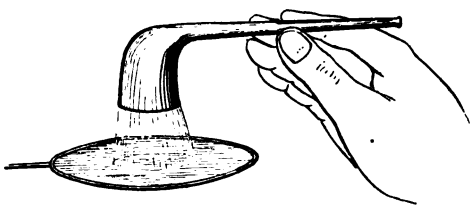


FIG. 112.

the lenses was four inches, his *telescope* made distant objects appear twice as large.

Now I dip this ring, blow a bubble and place it on the centre, then very carefully move the pipe a little closer or further away, leaving the pipe-end open to admit air. If I can succeed in getting the pipe free, we shall have a *little mushroom* (Fig. 112).

Those of you who have been in the kindergarten know that the first form you learned about was the ball. The next was ——? "*The cylinder.*" Have you any cylinders at home? "The rolling pin." Yes. There are cylinders to be found at the drapers—who can tell me? "The wood inside the rolls of ribbon." The grocer has some very wide cylinders, but they don't stand very high. Tell me what they are—something to eat, I mean? "Cheeses." Yes, that's what

I was thinking of. We can't easily make cylinders out of bubbles, but I'll show you how near we can get to the cylindrical form. I bring together these two ring-films so as to touch, now I draw them apart—not too far. But they are joined in the centre. I pierce the centre with this hot wire (Fig. 113).

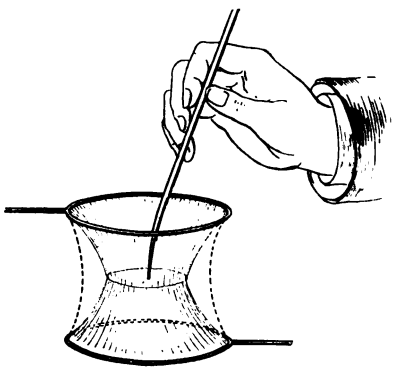


FIG. 113.

We had been considering, if you remember, the likeness of a soap-bubble to an indiarubber ball, and of a soap-film to a very thin sheet of indiarubber or bladder, or parchment of which the ends of drums are made. Bladder, you know, is similarly put on the tops of preserve jars. The next experiment shows very unmistakably the stretching power of a soap-film. It is a *Letter-balance* (Fig. 114). This slate is broken, but as the corners are "protected" you see the frame is quite good. I shall take off one of the short sides and remove the slate altogether. Now I file off the end of this knitting-needle, so that it will run up and down easily in the groove which has held the slate. I fix near the ends of the knitting-needle a piece of finest copper wire, turning it once round the needle and twisting the end below. One turn at the lower end of the triangle makes a loop, like that at the end of a toasting-fork. A little scale-pan is made out of the lid of a pill-box, and is hung by three strings to the wire loop. With a camel's hair pencil I paint over the

knitting-needle with soap solution. We can either put sand into the scale-pan or a letter. See how the film is stretching, the knitting-needle is bringing it down like a blind. Now we place a letter in the balance. I know that it weighs just half an ounce, so I can mark on the slate-frame with my blue pencil, the place where the knitting-needle stops for half-an-ounce. I see I was not mistaken in what would take your fancy! I will hang it up here. You shall make one for yourselves, and spend what time you please with it. You will then not easily forget how elastic the film is.

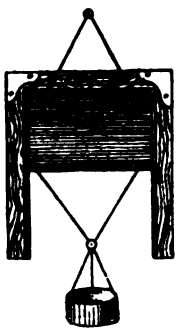


FIG. 114.

Now for our balls. I will blow a bubble on the ring. There it is! Now I blow another and hit the first with it. Did you see it spring back a little? They are quite separate and distinct still. I take this other ring and dip it, making a drum paddle or battledore of it. I hit the ball gently with it. Ah! that was too hard. I wanted to knock it against the first bubble, that you should see it bound off again. I will blow another and try again. Yes! we have knocked the first bubble off the ring and yet both are entire. With my battledore I can push this bubble now resting on the ring right through to the other side, if I am gentle. I can also press it back again. How funny! Stranger still, they have never really *touched* each other at all! There has been a soft cushion of air between the two—that is the secret!

I blow a bubble below the wetted ring as I did before. This time I take a larger ring, also wetted, and draw out, very gently, the lower end of the bubble. Now you see *a beautiful vase* (Fig. 115). (*Note.*—The bubble is not caught on a *film.*)

This time I blow a bubble over the fixed ring. With my disc of paper or the bottom of a pill-box attached to a knotted thread in the centre I draw down the bubble—of course wetting the disc first in solution. Now I can attach a little car, for the passengers. This shallow pill-box will answer very nicely. By careful management with the battledore I hope to be able to separate it from the ring and float it upwards in the air.

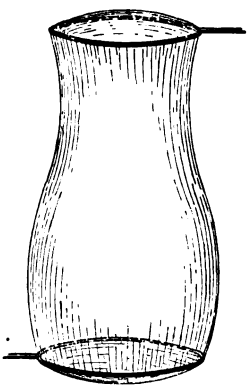


FIG. 115.

I repeat the experiment. As there are no passengers this journey, we will put a small bubble inside the first. There is no difficulty about this. I will show you a new way. Put the pipe through the ring (Fig. 116). Now set her off!

But let us not forget that these are Sunshine stories. There is a pretty experiment I wished to show you before, but time failed me. So far our bubbles have been seen by "all-coloured" or white light. You have seen the rainbow tints and learned their cause. You have also seen the *bands* of colour when undisturbed, as in the inner bubble.

I wish now to show you what a bubble looks like when viewed in "one-coloured" light, that is rays of one colour, in this case, yellow. I place some common salt in this saucer, and over it pour some (methylated) spirit of wine. Lower the black blind to the bottom, Charlie, and I will light the spirit. I blow a bubble. What do you think of it? No rainbow tints now! Now that the yellow

light has gone out I strike this red match. These red matches are the same which you buy for Gunpowder-plot. One of you brought these matches to school against the rules, and so they came into my possession. We used some before. I have held them in trust for you. They are helpers in the service of Sunshine. We will strike another one, and blow another bubble. You may draw up the blind for a moment.

I am now about to show you an experiment somewhat outside our subject, because I think it will interest you very much. After dipping the ring and re-placing the cork in the bottle, I turn the film vertically instead of horizontally. Now I blow a bubble and make it rest against the film. I blow another and throw it from the pipe against the first. They knock against each other, but will not join together. We noticed that before. Now I take this stick of sealing-wax and rub it on my sleeve, or that woollen muffler of yours, Albert. Like magic, before the sealing-wax has come near them, they have joined together. Is it not strange! You all ask me "why?" I can only tell you to-day that the rubbed sealing-wax has slightly altered the outside of the skin or film. Now we try the effect of one bubble inside the other. No, they won't join. The inside bubble is always free to

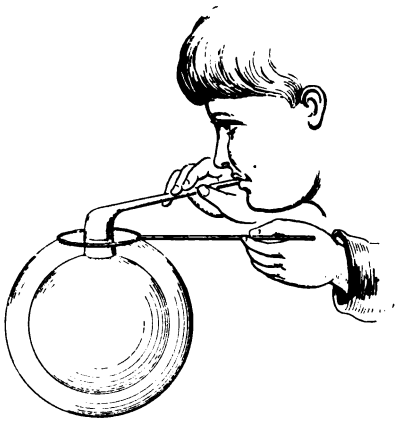


FIG. 116.

float about whatever happens. The rubbed sealing-wax only affects the *outside*. If you have no sealing-wax, use an indiarubber comb.

I have saved the prettiest experiment for the last. We must have the blind lowered for this, and allow the sunlight to come through the condenser and be reflected on to the bubble. First I call your attention to this aniline dye. I may just tell you in passing that these aniline dyes are prepared from coal which we learned stored up the sunbeams of ages ago. This green dye can be bought at the chemist's for a penny. The merest speck is put into this little glass of soap mixture. I shall first blow a small ordinary bubble, then put a green one inside through the ring without using my narrow tube, then you will please lower the blind. Notice how the outer bubble is growing larger as I blow the inner one; the inner one is pushing away at the air that rests between them. Now I allow the inner one to blow itself nearly out. See how it grows less; the outer one also grows less. Now I blow again and quickly withdraw the pipe. I must drain with the pipe the drop that hangs below the outer one. Lower the blind, please, and you will see them sail away.

Home Experiments

64. Make a skeleton prism with the wire that I give you. Examine this model.

65. Look at a star through your pill-box camera, shake the pill-box, observe twinkling and change of colour like rows of coloured beads.

66. With a little care you may float a fine needle on water. Lay it very gently on a piece of thin tissue-paper, and float the tissue-paper, which will presently sink and leave the needle supported on the film-like surface of the water.

CHAPTER XXX

SOAP-BUBBLES—PART IV

WHAT! not tired of soap-bubbles yet! I will show you an experiment which you will probably find one of the most easy and pleasing of all. I blow a bubble on the ring, and then applying a ring above it, I draw it out into a whole series of lovely vases, varying in form according to the amount of pulling. But I must not stretch the bubble *too far* in the hope of straightening the sides into a cylinder or we shall, like the boy with the nuts, probably lose all.

That is the only thing that I shall show you to-day in the way of bubbles. Let us now consider what they have taught us. The story told by our experiments is quite evident. The soap film is in a state of high tension, just like the inflated balloon, and is perfectly elastic, having the power of expelling air from its interior, with some *force*, as it contracts. Remembering how exceedingly thin it is, we are amazed at its *toughness* and *strength*. We have seen that the soap-bubble is perfectly round all over (a *sphere*), because the film is always tending to contract into that form which shall have the *smallest possible surface*. To give you a familiar example, there is less peel upon an orange than would cover the same orange if it were not *spherical*.

If oranges grew in the form of prisms or cubes or cylinders or lenses, they would require very much more peel to cover them.

You will be surprised that we are indebted for most of what we know about bubbles and films to Mons. Plateau, Professor at the University of Ghent, who was attacked by a terrible disease which entirely deprived him of sight, ere half his task was finished. Notwithstanding this sad affliction, he continued his experiments, with the help of his son and two devoted friends, who literally *lent him their eyes.* He says, "I constantly directed the experiments; nearly all were made in my presence, and I followed all the details." Then he continues the wonderful story of his experiments, just the same as before, with the same exactness about every little point in the working, until I—for one—fail to realise the fact that he has seen these things through eyes—other than his own. His experiments are most interesting. They were made with very great care and delicacy.

Plateau was anxious to know how a drop of liquid would behave if left to itself, free to take its own course. To give it such freedom, he must remove from it everything that might press it or push in any direction.

You all know that oil will float on water. Alcohol is lighter still; it floats on oil. By mixing alcohol with water, we may obtain a liquid *just as heavy* as olive oil. A bubble of the oil placed in this, is neither pushed up nor down. Having prepared the mixture of spirits and water, he poured it into a glass tank (Fig. 117). Inserting a glass tube, he introduced a drop of oil. It remained exactly where he placed it, as though it were a drop of the mixture itself in that place; it showed no disposition to move up or down or sideways. The little sphere of oil rested contentedly in the middle of the tank. At the top of the glass case (C)

you see a handle (A) fixed to a wire (B), having halfway down a tiny disc, around which the oil clings. When the handle is turned, the disc turns also, and carries the oil-drop round with it. Plateau noticed, that as he turned, the oil sphere became flatter at the top and bottom and bulged out in the middle just like our own Earth. As he turned more quickly, so the poles became flatter and flatter and the equator bulged more and more. Then the poles began to sink in, just like the top of an apple round the stalk. The equatorial region swelled so, that, finally the strain became too much for the elastic oil-skin to bear. As the speed increased, the central portion slipped off from the ball in the form of a ring. Though the ring was quite separated, it continued to revolve with the ball, as is shown in the figure. Does it not look like the planet Saturn?

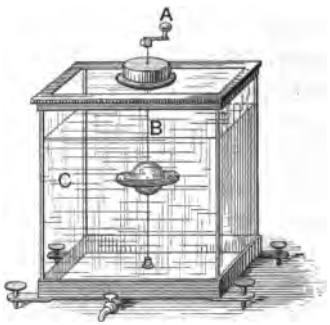


FIG. 117.

This does not in any generally accepted way explain the formation of the planets.[1] Yet we cannot fail to be reminded of them as we see these forms. As Plateau *slackened* the speed, the ring approached the sphere, and finally joined it. As he *increased* the speed, the ring shelled off once more. On turning faster, the ring was observed to break up into a number of spheres of various sizes, each turning on its axis, and all continuing their revolution round the

[1] This experiment of Plateau's illustrates the theory of La Place, who attributed the planetary forms to the rupture of cosmic rings owing to the condensation of the solar atmosphere.

central sphere, instantly calling to mind our Solar System (Fig. 118).

Dipping a fine tube into the mixture of spirits and water, he introduced some into the oil-sphere, making it

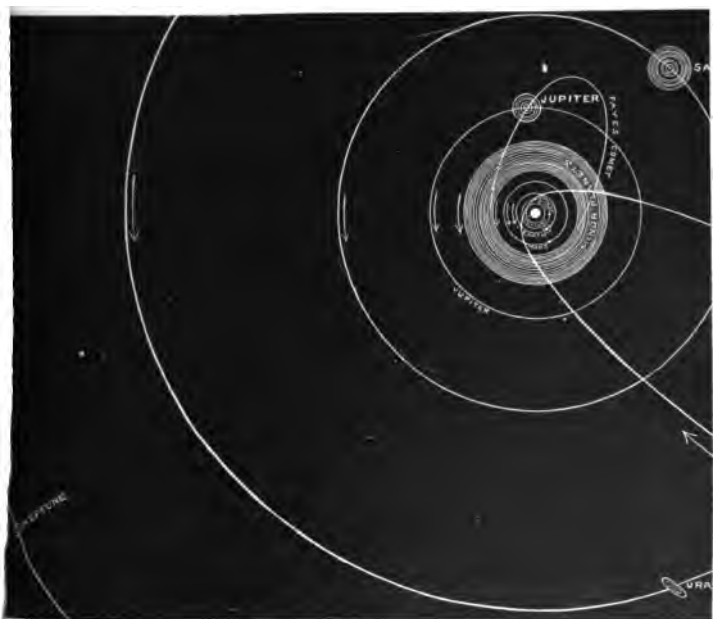


FIG. 118.—SOLAR SYSTEM.

into a bubble with a skin of oil, and full, not of air, but of liquid, the same as that outside of it. Bubbles could be made in this way, with a skin *so thin* that they would not have lasted more than a moment in the air. Yet here they floated about at ease within the mixture, helping Plateau to apply some very delicate tests respecting their properties.

These experiments show us that when a liquid is *free*, that is, not being pushed or pulled in any direction, it takes the form of a *sphere*, which we have seen has the *least outside of any figure*. No doubt you have been struck with this fact when you have watered the garden; you have seen the drops roll like beads down the raised flower-beds. This is only seen when the drops are *small*; large drops are too *heavy*; they are too much pulled. I can't go into the explanation now—they become flattened. You saw the *little* drops of mercury roll about (Fig. 74), but you may not have noticed that water does the same. To sprinkle some on a dusty floor is all that is needed. Our floor I am pleased to say is not dusty, so I shall shake some of this yellow dust (*lycopodium*) on a pane of glass, and then sprinkle water upon it, for you to pass round.

I promised to tell you something more about this curious dust—the spores of the club moss. I will show you just one other thing with it to-day, but we shall use it again very soon. I dust it over my hands, so, and then wash them in this bowl of water. Strange to say, the water has never touched my hands; for they are quite dry! There is one other experiment, though, which is most impressive, and perhaps more than any other will help you to realise the "skin," so to speak, that is on *water*. I dust lycopodium on this bowl of water so that you may see better how the *surface* acts. Here is a fine needle. I draw the magnet over it a few times (always in the same direction). I float it on the water quite easily, and now, holding my pen near, I can lead it up and down the basin anywhere. That is a thing you all know, but that is not the special point. Notice that the *water-surface* also follows. *That it moves along with the needle* is shown by the lycopodium.

Now that we have learned something about the be-

haviour of these films, let us see how far you can apply it to these films of Plateau's. You have each made a skeleton prism. I don't think you knew why? I will dip mine first. At one stroke, Nature has put in the equal windows! See, a thin film stretches from each edge of the frame, and yet I am afraid the glazier would smile and confess himself beaten, if asked to arrange his windows in similar positions. Examine it very carefully. You will not be surprised to learn that Plateau also made a *liquid* prism—not one of mere *films* like this one—and with it obtained a solar spectrum.

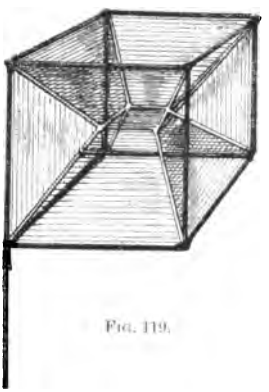


Fig. 119.

I have here a skeleton cube. How many windows will have to be put in this time? "Six." Well, we'll see! I dip it. This is the result (Fig. 119, the black lines stand for the wires; the *liquid edges* of the film are shown by the *white* lines). A flat film stretches across from each wire to the centre, yet not each to a central point, but to the corners of a tiny square film. Sometimes this film is horizontal, sometimes it is vertical. How very strange this is! Plateau found out the explanation. We shall see further illustrations in some other forms, which I have here. He discovered that—

(1) Never more than *three* films meet in *any edge*.

(2) Never more than *four edges* or six films meet in the same *point* in the interior.

(3) Films and edges respectively, make equal angles whenever they meet.

I do not mean that it is impossible to do otherwise *for*

a moment, but the films soon slide over one another and take up their proper positions. By blowing upon the figure, we may cause it to take up a slightly different form, *for the time being.*

By dipping the top square of my cube again into the solution, I shut in a small quantity of air, which forms a bubble and takes the place of the central square; in doing so, however, it must adapt itself to a square form, and becomes a sort of cube with convex faces (Fig. 120). It requires some practice to obtain the central cube, but it is quite worth while to try. (These forms are so very beautiful that it is impossible to give more than a general idea in a drawing. They cannot be adequately represented on a flat surface.)

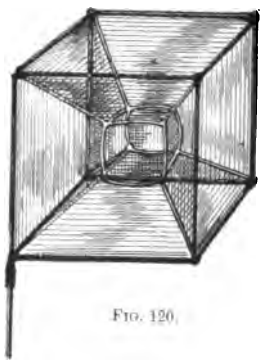


FIG. 120.

Now I take this ring and curl it round my fingers, or a round ruler, so as to half close it; see what a curious form we have here! It is convex and concave at every point, and yet it is not at all what we expected, for the plan of least surface comes into play, and as we look over it, we find that the top does not follow the curve of the wire.

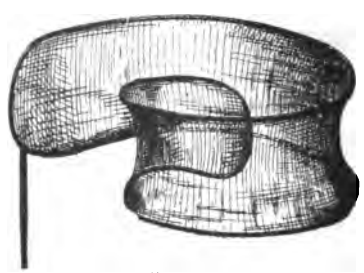


FIG. 121.

This next frame is made by bending the wire seven times at right angles. First make three edges of a square, then

leading the bottom wire away from you, complete three edges of the adjoining side. Complete three edges of the next side. The next turn of the wire completes the fourth side, and unites the same to where the frame was begun. Look at it; each face of the cube lacks one edge. You see what a very beautiful form the film assumes. Like the last, every point of it is both convex and concave.

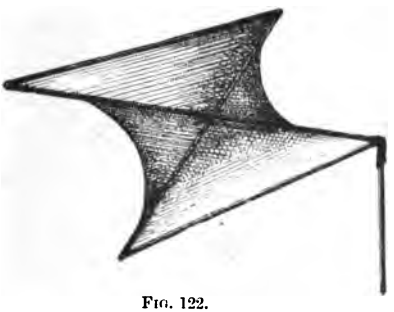


FIG. 122.

I now take a large ring and draw it out into an oval. I continue to draw it out until the long sides are straight and parallel. Take particular notice, for you can easily make this, and it is one of the most beautiful of all. I take it and curl it round this large ruler as often as it will go. You see the result (Fig. 121). I cannot describe it. Between the parallel wires, the outside surface is concave, because that has the least area; but the spiral form also makes it convex at the same time.

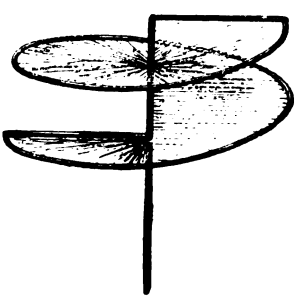


FIG. 123.

The next is formed by bending a wire four times at the same angle (60°). It looks something like a young bird's beak, when gaping wide. I know you will want to make this. You see what a very curious film is formed upon it (Fig. 122). The last frame that I shall

show you is a spiral. The film takes the form of a liquid screw (Fig. 123).

FIG. 124.—DIFFRACTION FIGURES. With a *round* hole Herschel saw coloured rings surrounding the images of single and double stars. *Triangles* gave stars with six rays. *Twelve squares (in outline) from the same centre* produced a star with four rays. With *rows of equal-sided triangles* he obtained (the last figure shown here) six-rayed stars composed of bright discs, each disc being surrounded by rainbow rings.

Now that you have seen these various frames I shall dip them in a mixture of resin, instead of soap solution. They

will not look so beautiful. You will not see the rainbow tints in them. They will look as if the films were of very thin glass, but the films *will remain* any length of time, provided they are *not too roughly handled.* I shall bring them back to school. These few forms have been selected for their exceeding beauty. I recommend you to make frames of your own, of whatever form you please, as varied as possible. You require no models, for you cannot go wrong. Remember what we have learned about the "least surface," about the equal angles, and the meeting of sides and edges. Notice also that the open air plays on *both* sides of each film—it is never "shut up" as in a *box*—unless we are able to catch and imprison an *air-bubble* as in Fig. 120.

Home Experiments

67. Soap-bubbles.

68. Cover the end of your pill-box camera with tinfoil, and make in it successively tiny holes of various shapes. Use it to look at the stars. They are very much brighter when seen through a lens or telescope. Therefore fix a micro-lens of Canada balsam in the lid of your pill-box. Sir John Herschel obtained the effects given in Fig. 124.

CHAPTER XXXI

A GREAT SUNSHINE REFLECTOR

SINCE the day I hung up Nellie's ball and illuminated it with the sunbeams, you have not ceased to question me about the moon, our Earth's particular friend and companion, as she journeys round the sun.

Let me see what you can tell me about the moon. Do you like her? "Oh, yes!" Why? She is so large and bright and beautiful, you say. Well, how large is she? Is the sun or the moon the larger? "The moon is larger." How do you know? "It looks larger." The moon is much smaller than the earth, but, as you say, it looks quite as large as the sun; that is because she is so near to us—nearer than any star or other planet. She is our nearest neighbour. It would take fifty moons to make one earth, and over a million and a quarter earths or $63\frac{3}{4}$ million moons to make one sun like ours. While, if we compare brightness, we should require at least half a million moons to produce as good a light as the sun gives us. Half a million moons would fill up all the sky that we can see!

What further can you tell me about the moon? "Please, teacher, the moon does not look round like our ball did, when the sunbeams lit it up." That is because you

are much further away from the moon, than you were

FIG. 125.—BABYLONIAN ASTRONOMERS.

from the ball. If you went near to the moon, it would not

look flat, but round like the ball. "I wish we could go near to it. Has any one been close to it? How did they find out the size of the moon?" I could not make you understand, until you can do much harder sums. "You promised when you gave us a lesson on the moon you would tell us how astronomers measure distances in the sky. That was why you left the ball hanging up there." I think I remember something of it.

The moon is 240,000 miles from us; that certainly is a long way compared with distances on this earth. To travel so far you might go ten times round the world. But in the starry heavens Moon-land is the first station from here. You have all been very much further than that. I thought I heard a little boy whisper, "I've never been anywhere." Let me see how many of you "have never been anywhere." You may well laugh at the gentleman who lives nowhere! You did not mean that, I know, Peter, you meant ——? You have never been away from home, you say; that is quite correct. Those who have been away from home, stand up! Where have you been?—and you?—and you?—and you? No one here has been more than sixty miles from home, and yet what I say is quite correct. You have been much greater distances than 240,000 miles. Even since you took your seats five minutes ago, we have travelled more than 5000 miles. Yes, now you can all tell me that the earth is going round the sun. You know it, because you have been told, and you repeat it without thinking, because it is not *real* to your minds.

Let us try to realise how Mother Earth, never stopping for a moment, folds us close to herself, covering us with wraps and clouds, and bears us aloft through space with a gentleness and tenderness so great, that we really cannot believe that we have journeyed more than a million and a half of

miles since this time yesterday, and that we are now moving on at the rate of more than eighteen miles every second.

Some of you have been on steamboats. I myself frequently have. Sometimes we are assured, in an uncomfortable way, that the boat is moving on. But on a river or a lake I have found boys very puzzled to know whether the boat had stopped, or was still going on. Then one would come and look out on the bank, and declare that we were still moving on. He could not tell by watching the steamboat, but by observing the flowers growing on the banks, and the houses and buildings which we passed.

Now, our earth-ship is very large indeed, and so long as we look on earth we shall seem to be standing still, just as the deck of the boat and the passengers appeared to be at rest. Where shall we look out for the objects we leave behind? Does that puzzle you? Look at the globe hung up there, and fancy yourself living on it; what would you see? The sky, you say. "Do we live in the sky, then? Oh, how nice!" Yes, we live on the earth, in the heavens; that is our address, though we don't very often correspond with the inhabitants of other worlds than our own, so we leave out those lines.

We must remember that the sky is not only above our heads, but is all around this world of ours. I will push this pin into an orange. Its coloured head shall stand for where we live. I hold it up in the heavens. The pin-head is seen at the top. Can we see the whole of the heavens at once? Suppose, Freddie, that you stood on that spot, could you see the stars underneath the globe at the same time as those above? "No." Why not? Because the earth is between. I will make a hole with this knitting-needle right through the orange. There, could you see

them now from the same place? "If we always have the stars overhead, why don't we see them now?" Sometimes I have seen a star or two shining when the sunshine has

FIG. 126.—"NUTCRACKS."

been only very faint, but usually we cannot see the stars in the day-time because of the brilliance of the sun. Just as you cannot see the light of a candle, when the gas is lit. Did you ever try? If not, do so.

If, some day, you could get your father to take you to that old mill that is "to let," and you were to look up the long chimney, you would see the stars in the broad daylight, for your eyes would be screened from the direct rays of the sun. I saw Mary Brown yesterday, in the playground, hold her hand above her eyes for the same reason, as she looked for her sister Florrie.

Then you must look out in the sky, every night, if you would know that we are journeying on. I often wish that I could meet you in the evenings to tell you the names of some of the stars. Ask some one to tell you. You will find that we leave the stars behind, just as we leave the flowers and buildings on the river-bank. Each season we pass different stars, on our path round the sun. The stars which we pass to-night, we shall not pass again until we journey the same way next year.

Now, can you tell me how many moons we possess—we seem to have so many new ones? What becomes of the old? Ah! you have heard the story too. Do you really believe, that they are chopped up to make stars of? The stars are *Suns*, many of them larger and brighter than our own, and you know how many such stars our moon would make! Is the moon always of the same shape? You don't think so? Well, let me see if I can make that clear, because if you believe in half-moons and quarter-moons, you have begun to chop it up already.

I lower our black blind and flash the sunlight upon the ball with this mirror—so. George, are you the boy who manages the mirror so well—come and stand on this form by the window. Now, as the ball is in the middle of the room, high above your heads, some of you will see the moon shining and some will not. Those who see the moon *at all*, stand up! Don't you see the moon—at the back there? I

will come over and look. You are right, there is no moon *visible*; but it is there all the same, for the children in the

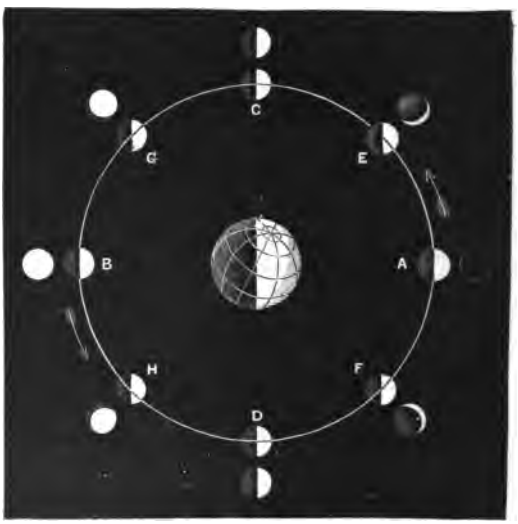


FIG. 127.—PHASES OF THE MOON. (The Earth is in the centre, the Sun is a very long way off to the right.) This diagram shows how half of the moon *is always lit up with sunshine* as she journeys round Earth. Outside the circle is shown *what the moon looks like to us* at the different stages of her journey. A, *new moon*; we see no moon for a day or two. E, *crescent moon*; we see, just after sunset, a little of her bright face in the west of the sky (the horns always pointing away from the sun). C, *first quarter*; about a week after new moon the half-moon rises at noon, and may be seen in the south about 6 P.M. G, *gibbous moon*; we now see more and more of her bright face every day—all except a little bit on the left. B, *full moon*; on the fifteenth day after new moon we see *the whole of her bright face*. The full moon rises in the east *just as the sun is setting* in the west, and may be seen till she sets (at sunrise). We now see less and less of her bright face. H, *gibbous moon*. D, *last quarter* (the moon now rises at midnight and sets at 6 A.M.) F, *crescent moon*. After this the rim of light grows very thin, and vanishes a day or two before new moon.

front desks see it. Now I walk round the desks a little further to the right. I see a faint glimmer of light round the edge of the moon. It is *new moon* where you are sitting,

Charlie. I shall put a cross on the floor and write "new moon." At new moon, the outer curve is to the right hand.

Still continuing to go round the desks to the right, in a circle, the moon appears larger to me at each step. As I stand by you, Edith, I distinctly see the two horns pointing to the left. At my feet I write the word *crescent*, which means "growing."

Now I have gone a quarter-way round the desks, and come to you, Nellie. You see the *half-moon*; I will mark half-moon on the floor. Where you are, Charlie, you see the moon nearly full. The word [1] is a hard one. It means "hump-backed,"—that is what I shall write, and one which you will easily remember. Now I come to the full moon with the sunbeams lighting up the whole face. All this while the moon has been *waxing* or growing, as it has seemed to me.

I shall gradually lose sight of it. The moon is now *waning* or lessening. I see the "humpback" again, and now the waning half-moon is just opposite where I saw the growing half; and now I see the crescent moon with horns to my left, this time; and now no moon, at all. Try to remember that the horns are always turned away from the sun. All these places I have marked upon the circle on the floor.

If you think you could come very quietly out of the desks, round this line, and keep your eyes fixed on the moon all the time, you may try. Walk very slowly round, standing for a moment at the places marked. You may go round, once more, very slowly. Right about turn! Take your seats quietly in the desks!

By the side of the large ball, which measures four inches through, I shall hang up this little halfpenny

[1] Gibbous.

ball, which measures just one inch in diameter. You may look upon the large ball as the earth, and the small ball as the moon. Just now, we passed round the moon, and you saw the different appearances, or "phases" as they are called. The effect is the same in this case, whether we go round the moon, or the moon goes round us. To-night at home you may call yourself the earth, and take an orange or ball in your hand for the moon. Placing the lamp on the table above you, stand still in front of it, and carry the little moon round you above the level of your eye. You will then observe the changes of the moon.

To-day we hope to have a somewhat closer view of your old friend. How far is she away from us? (240,000 miles). How do we know that? "You promised to show us how to measure distances in the sky." Is that why you have beside you, your father's measuring-line, Teddie? We might measure the distance of our little moon, so, if you were to climb up above my table, but that would not help us much in estimating sky-distances. The plan is very much simpler. You see the ball hanging above the middle of my table. Ernest Smith and Rosie Thompson, come and stand, one at each end of the table. Ernest, here is a square envelope. Fold down one corner to such an angle (which you will find by trying) that when you put it to your eye, one side will point to Rosie's face, while the other side will point to the ball. Should your angle be too big, then, when you see Rosie's face along one side, the other side will point *above* the ball, instead of *at* it; while you will see *under* the ball, if the angle be too small. Rosie, your angle must point to Ernest along one side and at the ball along the other side. Now that you have folded your angles correctly, I will cut off the paper which is left. Teddie, you may measure the length of the

table from Rosie to Ernest. "It is twelve feet," you say.

Now we shall make a small plan on the blackboard. Let one inch on the plan stand for one foot of the real distance. How long then shall we make this line, which represents the table? "Twelve inches." Right. At the end of the table where Rosie stood we will mark R (for Rosie), at the other end we will mark E (for Ernest). With drawing-pins we fix Rosie's angle at A, Ernest's at B, just as they were held, so. Now we place our ruler along the opposite edges of the same, and draw two long lines which cross each other—at that particular point, we put the letter B (for ball). Now we measure with Teddie's line the distance from R to B, and find it to be twenty inches, likewise the distance E to B, which is the same, as the ball hangs over the middle of the table. Now, can Rosie tell me how far the little moon was from her sight as she stood at the end of the table? "Twenty feet," that is quite right. And how far were you from the moon, Ernest, at the same time?

At home to-night you each may try to measure the distance of some high object, say, the nail from which some picture is suspended, or the highest peak of grandfather's clock. You shall each choose your own object, either indoors or out, *e.g.* you might measure the height of a tree or the church-steeple. Do not stand too near together, but as far apart as is convenient.

At the beginning of our "talk" about the moon, I tried to impress upon you what old travellers you were. Do you remember how far you have been each year? (585,000,000 miles.) And you, Tom, are —? "Seven." What age are you, Percy? "Eight." And you, Minnie? "Nearly eight." You shall work that sum out for me on your slates. We will neglect the travelling since last birthday. Multiply

585,000,000 by eight, Percy. Four thousand six hundred and eighty millions of miles, you say. Have you felt any pain or sickness? Are you willing, then, to accompany me

FIG. 128.—"THE GINTLEMAN WHO PAYS THE RINT."

for a little "out" to call on our next neighbour the moon? It is only 240,000 miles, and would take us a little over three hours and a half at Earth's usual rate of travelling.

Do you think your mothers would trust you with me if I guaranteed to bring you safely back again? Most of you say "Yes." What is it that Ethel is saying to you, Lucy? "She wants to know if we are really going, or if it's 'only pretending.'" That is a question which Ethel must decide for herself. Those who are going with us must be ready in time, or they will be left behind. Before we make a journey it is usual to consider, not merely the distance, but a few other matters also, such as —? "What to take with us." "How long we shall be away." "Where we can get lodgings." "Whether we should take shawls, umbrellas, etc,"—and so many other considerations that I am afraid we can't go to-day. Make all inquiries at home, and let me know how many of you are prepared to go.

Robert Greenwood, what were you going to ask me? "Please, teacher, is the moon kind to the earth?" Well, children, what do you think? I believe that before we learned how necessary the sun is to our very life, many of you would have given the sun in exchange for the moon. Would you not? You love the pale soft moonbeams that do not interrupt your view of the stars. Though I am sorry to say that astronomers are not very fond of moonlight nights. They tell us there are very few perfectly clear dark nights on which they can see the stars so well as they would like.

Perhaps some of you, when at the seaside, have watched the tide come rolling in at your feet. Sometimes the wave has caught you before you could run back—then how you have laughed, and perhaps, for the moment, you thought you were going to be drowned! Or you built castles on the sands and dug a moat around. Then you waited by, and watched the big wave come rolling up to it and level it to the ground in one great sweep. Then you cried for joy!

When the tide turned, you picked up shells and seaweed on the beach as they were washed ashore, and you followed on and on by the water's edge till you found yourself ever so far from the promenade, quite half as far out as the end of the pier. I daresay you wondered very much, and thought very often, about these *tides* that came twice each day; but did any one tell you that it was the moon's pulling at the water which made the tides? Tides are helpful in many ways that I cannot speak of to-day, because I have only time to tell you how valuable the moon is to the sailors when guiding their ships, full of passengers, over the great oceans. When seamen sail far out of sight of land, how may they know where they are? They look up to the stars to know the time. The blue sky above their heads is Nature's Clock-face. The stars are the figures on the dial. But a clock-face with figures won't tell us the time, will it, Albert? Look at our clock—how do you know the time? "By the pointer—by the hands, teacher." Yes; and the "pointer," as Albert calls it, in Nature's clock is—? Can nobody guess? No, that is strange! Why, the moon is the pointer, as she moves about among the stars—now close to one star, soon beside another. The sailor looks to see what star the moon is near, then he makes a little calculation and looks in his almanac—funny! isn't it—and then, not only does he know what time it is, but how far he is, east or west of London. Often, after several cloudy nights, when no moon was to be seen and the sailor had to rely on other ways of finding out, he suddenly rejoices to see the moon's glad face visiting among the stars—he opens his book, finds that he is a long way from where he supposed, and thanks the moon for having shown her sweet face, just in time to warn him that his ship was pursuing a dangerous course, and to guide him into the right direction.

Home Experiments

69. Look at the street lamps, at night, through a handkerchief.

70. Look at a distant candle-flame, through the fingers nearly closed.

71. Take a walk when the lamps are lighted in the evening. Observe the curious movements of your shadow on the ground. Describe exactly what takes place. When is your shadow longest?—shortest?—before you?—behind you? At what point does it pass you? Is it always on the ground? Is it ever on the wall? How is the wall-shadow caused?

CHAPTER XXXII

A MORNING IN MOON-LAND

YOU all look very bright and happy this morning, and I perceive that you have not put on your usual frocks and suits! May I ask—though I don't like to be rude—what occasion we are celebrating to-day, that you should be so gaily attired? Several of you girls, I see, have your hats on. Alfred, your cap is on the desk! Where are you going? "We are going with you to see the Moon Country. Don't you remember, you promised to take us?" Well, then, I suppose I must, though I little expected you would regard my joke seriously! You really wish to go?

"Oh, yes!"

Have you made your wills?—insured your lives? I suppose your luggage is safely sent on in advance?

"We are not taking anything but these shawls and umbrellas, because you said it was only the next station."

—In the starry heavens, I think I said. It is 240,000 miles' journey. The sun is nearly four hundred times as far away. Well, if you have sufficient food I will take you, for I see that you have provided plenty of wraps, and you will certainly need them when you arrive. But first I must endeavour to make satisfactory arrangements with the

authorities, to ensure our safety and convenience. I will try to have some of the conditions of life in Moon-land slightly modified in our favour.

"What sort of conditions do you want altered?" You would like to be permitted to hear each other's voices?—to escape injury from showers of dark meteors, which at times rain in torrents on the lunar surface, with a *force* compared with which cannon-balls are but as corks from a pop-gun? You would not like to endure an afternoon so hot as to melt lead, or a midnight cold of some 200 degrees of frost?—nor to feel the convulsive tremors of the rocks grating, chipping, and splitting *in awful silence* beneath your feet?

"Do they? Why, how's that?"

That is because of the sudden cooling of the intensely heated rocks after sunset. A visit to the moon will teach us how to value Earth's misty cloak, which she folds so tenderly round her children; but perhaps it would be better not to go?

"No; we want to go and see it all for ourselves."

But you wouldn't be able to breathe!

"Couldn't you arrange about that, too?"

I don't know, indeed! I must have time—perhaps to-morrow. . . .

"Oh! we've got ready to go; take us to-day, do, please."

. . . . . .

Now those who are going with me must take their seats in the desks. Our ship is so large that I don't think you will feel the movement uncomfortably. A terrible responsibility rests with me as captain, and only those may go who have learned to obey orders *instantly*. I shall require you to close your eyes until we have got fairly off and over the most difficult part of the journey; but you will not be

lonely, for you will hear my voice all the time, and you will hear your companions' also after we have passed the points I spoke of. Do you agree?

(*All*) "Yes, teacher!"

You have seen the moon many times; do you see her now? If you will close your eyes you will see the moon. Try! Yes, you all see her; that is right! Keep eyes fixed upon her; she will grow brighter and brighter every step of the way. She is very much brighter now—*very* much brighter and larger and rounder. Is that so? Yes? Now keep eyes *fixed* upon her; don't lose sight of her for a moment. In doing so you will help me to steer. If you take eyes off her we shall probably go wrong. I trust you. Now, after I blow the whistle, do not speak until I give you leave. (*Whistle.*) . . .

Now that we are fairly set out on our voyage, tell me what you think Moonland is like. You very likely expect to see the "Man in the Moon," who is said to have been sent up there for gathering sticks on Sunday. I don't promise you that treat, but perhaps a closer view of himself and his sticks may reveal something very unlike either.

. . . . . .

Now that we have soared some height above our usual resting-place, you may open your eyes. You see the desks, you say! Did you not expect to see the desks? Certainly! certainly! We always see the vessel in which we are travelling. Do you forget so soon, the travels you daily make in this schoolroom? But look above! See how much more brilliantly those stars are shining than when we viewed them from earth! Do they not look like diamonds in the sky? When we set out, there was not one to be seen through our atmosphere. No, Freddie, we are not very much nearer to them. They are still so far away that

the light shining now in our eyes has taken more than three years to come from the nearest of them. They do not twinkle, for twinkling we found was due to our atmosphere.

"I know now why you told us to close our eyes—but how black the sky is!"

Yes, you remember what we learned about the colour of the sky—how the varied tints were caused by our atmosphere's stopping certain colour-rays on the way and allowing others to pass on. The atmosphere is Earth's very own. It clings around her for at least a distance of 200 miles, and probably very much further, but we cannot take it all the way with us. We are now very far beyond—in fact, very near to Moon-land.

"Oh! what was that which flew past us at such a rate a while ago?"

Only a meteor, or "shooting-star," as we are wont to call them. We shall meet tens of thousands of them on our way, but we shall not see them as bright stars any longer. They, too, are journeying round the sun, yet in a very different path from our Earth or the other planets. Where the roads cross, Earth meets the little bodies and gives them a great, swift pull towards herself, just as if she were striking a match. Chafed by our atmosphere on every side, the meteor is whirled, swifter than cannon-ball, becoming warmer and warmer—intensely hot—until finally he takes fire—burns completely up before reaching our Earth's surface.

"Please, did you not tell us that wind was air in motion? If there be no air, how can our ship sail?"

That matters little indeed for a voyage in the heavens. We depend on mightier forces than wind. I should advise you to close your eyes until we are in port; we are not far away, and I cannot promise to return you safe and sound unless you obey implicitly my instructions.

When you open your eyes we shall have landed on the surface of the moon, near the centre of the bright disc which we

FIG. 129.—THE MOON (Third Quarter).

see from earth. The mountain to the south of us is called Ptolemy. We shall not be able to see it in all its grandeur

when we land, for it is night—midnight, in fact. The moon is now growing larger and larger, very rapidly. Only a little portion of it is to be seen, on which we are about to land. . . .

We have landed. Open your eyes! You see the mountain; but, you say, it can't be midnight, and we must have come a long, long way, for are we not quite close to the Sun? —he looks such an immense size, that you are frightened, and it is, oh! so *cold*. What a tale! Shall we go back then? I will take you home at once, if you prefer, Davie.

"No, no, no, it's splendid!"

Davie says he thinks it's splendid too, but he is afraid. I suppose it is because of the dense shadows which the mountains cast upon the plain. Perhaps he will be reassured, when I convince him, that the object we see is not the sun —how could it be while we are so cold? Wrap up, children, and let us look well at that glorious orb which seems to be *hung up* in the sky overhead. Do you know, children, that this *black* sky makes us magnify objects—that is, we see them brighter than usual because we are able to open wider the pupil of the eye. This enables us to see hosts of stars and planets too faint to be seen from earth—even right down to the horizon, where clouds usually hide them from us. But we cannot say, "Twinkle, twinkle, little star" here!

But the glory of the stars is as nothing compared with that immense bright object which first met your gaze—if I may judge from the strange fascination it seems to have over you, and your disputes as to what it is. "It's the moon because it shines at midnight." "It's too big for the moon." "Why, we're on the moon." "It's the sun; nothing else is so big." "No! for teacher says it isn't the sun," you say. I wonder how soon you will settle the question! I quite agree with you that it is too big for the

moon. Its face is nearly four times as broad and *thirteen times as large as our full moon.* It cannot be the sun, for we are scarcely a step nearer to the sun than we were on earth. The sun is nearly four hundred times as far away from earth as this; so that you may expect the sun to be very little larger than usual when we see him, as we hope to do by and by.

Do you know, boys, Percy, who has been gazing intently, while you have been discussing the point, has just whispered to me that he thinks he is able to make out the continent of America; and if that be so, he has settled the question for us. Yes, that is "Our Home" which we have left behind! Duncan says he thought so all the time, but he was afraid we would laugh at him for saying so—he didn't know our earth shone like a great, great, great big moon. Yes, look well at it, children, for that is why I brought you here. I love to think our home is so pretty! Here we see to perfection Mother Earth's misty garments. She seems to be fixed, "hung up," as one of you said, in the sky, not sailing along like the moon. The stars, as they pass behind her, do not disappear as they do behind our screen-like moon. No, the stars are "caught," as it were, in her veil, which, refracting their light towards us, makes all kinds of distorted images of them, and these distorted images of so many stars give that peculiar glow or haze of light seen round the earth; whereas our moon seems to have a sharp clear-cut edge like a coin.

By and by we will explore the country, but while earth remains "full" let us make the best of our position. Then after you have had a sleep, we will walk over to one of the most interesting spots in Moon-land, and we will watch sunrise from the mountains.

We came here, because it is the best place for seeing

Earth. From other parts of the country, nearer to the edge of the disc, she is only visible near the horizon, even for a short while. From other places, round the edge, as we call it, Earth is scarcely seen at all.

"Can the people on earth see us?"

They cannot. Nor can they see Moon-land, for at present the moon is "new" to them. The phases are just reversed—"new-moon" to them, "full-earth" to us; "full-moon" to them, "new-earth" to us. At lunar sunrise, if we stay so long, we shall see half-earth, which will slowly wane to the crescent-earth in the long lunar forenoon. The crescent will grow narrower and narrower till noon, when the sun will be in a line with earth, which will then be invisible, except for the thin rim of light marking its upper or lower half. In the afternoon we shall see, on the other side of earth, the illuminated crescent, which grows and grows, till at sunset we again see "half-earth."

Now that you have gazed so long and intently upon earth, tell me what you have been able to make out? You ask me, what part that most brilliant white light comes from. It is reflected from snow and ice. You may perhaps observe the ice-cap covering the South Pole. In winter the ice-cap round the North Pole is very plainly seen. But the face of the earth is sprinkled over with spots. Many of these are fleeting clouds, and as these pass by we distinguish, in the brighter patches, the forms of the continents. The varying tints of yellowish-brown and green represent land in different stages of vegetation. The pale blue-green stretches seen in the lower portions of the disc are the great oceans. If we watch carefully we shall distinguish Europe, Asia, Africa, America, and Australia as they pass, for earth at "full" will turn at least once round before us.

You say you don't understand, why the earth doesn't sail along like the moon! Let me see if I can make that clear. You know that our earth turns right round in one day; but I daresay you never *realised* that fact until now. It seemed, instead, as if the Sun went round the earth. You saw him rise in the east, and noted his arch-like path in the sky till he "set" in the west. A little later you watched the moon and the stars do the very same thing, apparently. If the Sun rose at six, he set at six. If he rose at five he set at seven; and so on, the two figures always adding up to make *twelve*. Now the moon's day is twenty-eight times as long as ours. From the moon, the sun planets and stars appear to pass across the sky in precisely the same way; but they have twenty-eight times as long to do it in. Therefore, *they move twenty-eight times as slowly.* Try to understand all that you see! I am glad that you have asked me that question. Now I think that you ought to go to sleep. I will waken you in plenty of time to see the sun rise. Yes, you shall watch earth when I have wrapped you up well. I would not deny you that pleasure. You will fall asleep before long.

. . . . . .

I am afraid you will be very disappointed with sunrise, for you will see none of those glorious tints of crimson and gold shooting out of the grey mist, streak by streak, as we do on earth. You know by this time not to expect anything of the kind, and you know why. We are now about to enter upon three hundred and four hours of sunshine.

"But isn't it going to be dark first?" No, it never is dark on the moon—"the darkest hour's before the dawn." It never is darker than it is at the present time, and, as you see, the light from half-earth is many, many times brighter than the brightest moonlight night ever seen on

earth. Well, Robert, you want to know why we have come up the mountain to see the sunrise. "We came to see Copernicus; we are going to inspect the crater when it is fully lighted up; don't you know about it? Why, I've been awake ever such a while, and we've had such games and sports!"

No, Donald, that is not the whole reason, besides we must think of going home. The fact is, Robert, we are now on such a little world that we have to climb to a height to see any extent of country; we want to see as much as possible over the "edge" of the moon. Another reason is, that in the absence of atmosphere we can form little or no idea of distances or the size of objects; those in the distance appear just as distinct, and near at hand as those in the foreground. It is only by seeing as much of the country as possible at a glance, that we can reason out for ourselves the distances and proportions of objects, by taking note of the country which lies between them, and so help our eyes to judge correctly.

"When the sun comes out, will you take us another walk and show us all around here?"

What would you like to see best? Sidney says he would like a drink. Now that is very awkward, Sidney, for there are no drinking fountains here, no river, not even a mountain rill, whichever way we look. I am afraid you must wait till we return. Where would you like to go, Andie?

"I should like to gather some flowers to take home with me."

Where could we find them?

"Down in the valley there."

It will be fully noon, before the dense shadows of the peaks creep off that valley, and then I am afraid you will

be disappointed in your search. However, we will look presently. Sam, where do you wish to go?

"I want to go and see what animals live in such a bitter cold country. I am sure there must be bears and seals not far away."

You may be inclined to change your opinion about that in less than an hour! Dick says he's looking out for birds, but he has not heard a single chirp or twitter — have you? He says he's quite anxious to see the inhabitants of Moon-land, but he supposes no one is up yet!

Ah! what do we see over the hill-tops?—a pale, faint light. Perhaps you thought the herald sunbeams were on the way to announce their lord, eight and a half minutes in advance; but if so, you will be disappointed, for without atmosphere, there is nothing to refract the light. King Sol will suddenly dart upon the scene without a trace of crimson or gold-tinged *cloud*. We shall see him, *as he is*, with his ever-changing crown of glory (Fig. 63). We shall see his red prominences or leaping flames. He will also be attended by the zodiacal light, which is not seen from our part of the world. It is the faint glimmering of that light that we see just now. Yes, he will shine in this pitch-black sky full of stars, and we shall see Mercury quite close to him, and Venus, and many stars which we rarely see from earth. Then we shall exchange this perishing cold for the most terrific heat. You ask me why the half-earth is nearer the horizon now—she was overhead before. It is we, who have changed our position. We are now in the north-east portion of the disc, seen from earth.

"Oh! can they see us from earth, yet?"

No, they cannot even see the disc till the sun shines on it, and even then they cannot with their very best telescopes see us.

"If they couldn't see *one* of us, perhaps they might see the 'lot' of us, though."

No, not even the "lot of us," nor the whole school of us, if all had come—aye, the building included.

"Well, perhaps they could see this mountain?"

Yes, that is quite possible with a telescope; and when you go home you can tell them exactly where you've been. Now that half of the sun has gradually risen out of the black sky, you see those wonderful features I spoke of. But this heat is terrible, with no atmosphere to shade us. I fear we shall have to take refuge where those long awful shadows tell us that the sun has not yet emerged in all his majesty—there, it is freezing cold still!

"Teacher, how do you know your way about on the moon? Have you been here before?"

No, dear, but the geography of the moon is far better known than that of some parts of our own land, *e.g.* Australia and Africa. Here in the north we have the Alps, the Apennines, and the Caucasian Mountains. There are other mountains than these named from earth, *e.g.* the Pyrenees, Altai, Carpathian, Oural Mountains, etc. Those dark patches we observed from earth are still called seas, though now they are but empty hollows.

Now we have fully entered on possession of our lunar day, for over three hundred hours King Sol will reign here in full splendour. Did you ever see anything so magnificent? You never *saw* the Sun before. You saw but a central disc and haze of light around. 'Tis only during eclipses that on earth we see these solar appendages, as they are called. How near he seems, and if we were not specially protected, we could not endure the fierce glare of such a sun for a moment. It is like a monstrous electric light held close to the eyes. The highest mountain peaks are bathed

FIG. 130.—MORNING IN MOON-LAND. Ideal view in the neighbourhood of Aristarchus. Aristarchus is the most brilliant crater in the moon, so bright indeed that it has often been seen in the dark side of the moon, just after new moon, and has thus given rise to the marvellous stories of active lunar volcanoes.

in light, but their slopes and the lower peaks as yet, and for many hours to come, lie overshaded in densest blackness.

"Yes; why are any parts so black in this blaze of light?"

Have we not learned that the more brilliant the light, the more intense is the shadow it casts? At present the mountain peaks are standing in each other's light, but he will soon look over their heads, and pour his beams straight down upon them. When first we saw the sun, our circular mountain-top was dimly visible; its centre was filled with darkness, so to speak; but while we have watched, the top of the wall has gradually put on a garment of dazzling brightness. The vast rim of the crater shines like an immense silver ring, and within it we see, one after another, rise out of the dark shade, a group of silver-topped cones. As the light creeps down, more and more of them rise into view, and we wonder how many will yet appear! It will be noonday, before all the heights about us are completely bathed in light, and then we shall see no more of Earth, for she will be in a direct line with the sun—yea, we shall just see that rim of light, we spoke of. Let us take a survey. One more look at Earth. The crescent is very, very narrow now, and looks as if it belonged to a much larger disc.

. . . . . .

In our ship again! How glad you must be to get home; do not open your eyes, but look out upon Earth and watch her grow larger and larger, rounder and rounder, until you can see only a small portion of our town.

I am sure you must be very tired! While we journey, you shall talk to me at the same time. I shall be happy to explain anything which has puzzled you.

"I should like to know more about those prominences."

Why we don't usually see them from earth, do you

mean? The Sun lights up the sky round about him. It is only when the dark body of the moon cuts this illumination off that we are able to see those parts. They are usually "*put out*" *with too much light.* The sky is common property, but the clouds, through which we ordinarily view its wonders, are *ours.* King Sol lives in an ocean of glowing hydrogen, for that is principally what these flames show themselves to be. This ocean surrounds him for about 50,000 miles, though in some parts the flames leap out to a distance of 70,000 miles. Now, tell me something—did you find the objects of your search?

"No, but we had some jolly games; we were just in the midst of them when you came up to us, that time."

What did you play at?

"We began by playing 'leap-frog,' but we always jumped too high. So we decided that we would stand straight up to be jumped over. Then we found that was too low still, so Tom stood on Ernest's shoulders, and we jumped over both of them quite easily, and formed ourselves in twos after, for the others to jump over. We went on in this way, till we could jump over five boys. And the fun of it was, we didn't feel a bit tired with four or five boys standing on our shoulders."

What did you girls do?

"We played skipping-rope by jumping over the rope when it was at its highest point. And Harold brought his kite with him, and tried to fly it. He forgot there was no air. He made us all laugh!"

What else did you do?

"We saw quite a little crater, and we all raced off to look what it was like."

What was it like? Don't all speak at once. You tell me, Richard.

"I don't know how to explain it; but I could show you how it was built, if I had a plate of pears."

A plate of pears! You funny boy! I am sorry I haven't any for you. Take off that Scotch cap and put it on your knee for the dish. We shall have to imagine the pears.

"I should put a little pear in the middle with its point upwards, and then I should put the other pears round the edge the same way. That isn't quite like the crater, because the mountains round are not quite so distinct and regular as the pears."

If you were showing this at home, you would have to represent the shadows also. How would you do that?

"I should light a bit of candle and put it beside the plate."

That would do very nicely. How does the little mountain get in the middle of the crater, Charlie asks. You have all heard of volcanoes—mountains that send out fire and streams of lava and great showers of ashes. We have at least a hundred such mountains, on our earth, which break forth from time to time, but none so large, nor so furious as once raged upon the moon. You have heard of our Mount Vesuvius or of Mount Etna. A few years ago there was a terrific eruption at Krakatoa. It made the loudest noise ever known, and shot up so much dust into the air that it was carried to almost every part of the world. Besides these *active* volcanoes we have a number of *dead* ones.

Some of you, I know, have climbed up the steep rocky path to Edinburgh Castle. Thousands of years ago, those rocky walls were formed by the cooling of the liquid lava shot out from the great fiery heart within.

Sometimes when the convulsions have ceased, the lava streams cool down on the mountain side, and to all appearance the volcano is dead. Suddenly the mountain gathers up all its strength into one prodigious effort—a kind of

dying gasp—and succeeds in forcing through the centre of the half-solid crust, a great quantity of material, and in this way, the peak you saw in the centre of the crater is formed.

"Is there no air at all, on the moon?"

There is no atmosphere which will compare with ours, though occasionally a *trace* of air, or some kind of gas spreads as a fine *thin veil* over the lunar valleys. How do we know this? We have seen that air is not perfectly transparent. Our "artificial sunset" experiment showed us, that when the all-coloured light of the sun, had to pass through *a great thickness of air*, as at sunrise or at sunset, not all the colour-rays could struggle through. After our Sun has disappeared, the thick atmosphere produces, for a little while, a refracted image of him, just as the penny was seen in the basin.

Now this is not so in the case of the moon. When the moon passes between the earth and a star, it hides the star *almost instantly*; whereas, if the moon had an atmosphere like ours, the refracted image of the star would linger behind for some minutes.

We are so very near home, that the ship demands all my attention. Close your eyes and help me to steer. When you open your eyes our "School" ship will have returned to the docks, not very far from any of your homes, and we shall all have to take leave for a short time.

. . . . . .

Open your eyes! We have now arrived at the landing-stage, whence we set out. Good-bye, little folks! Tell the dear ones at home of the bright star-world we live in. Be determined that nothing you shall ever do or say shall in any way dim the lustre of that small portion for which you are responsible, and over which your little feet daily tread!

Home Experiments

72. In a room where there is no other light, place a lamp on the table, just above your head. Take an orange or ball in your hand to represent the moon, and look upon yourself as the Earth ; carry the little moon round, above the level of your eye. You will then observe the phases shown in Fig. 127. When the ball hides the light of the lamp from you, that will be an eclipse of the lamp (sun). When your head stops off the light from reaching the ball, you will have represented an eclipse of the ball (moon).

73. Take a companion with you, and measure the height of a church steeple. Provide yourselves with a ball of string. Go as far apart as you conveniently can, and stretch the string upon the ground for the base line. When you come in, measure the string used, and draw the plan.

74. Look at the sun through a black silk tie, handkerchief, or ribbon.

CHAPTER XXXIII

THE LAMPLIGHTER OF THE THREE KINGDOMS

A SHORT time ago I was taking a walk along one of the long roads leading through Cheshire into Derbyshire. After watching the sun set, dark clouds presently drew over the sky. No moon came out to welcome us, nor any stars, yet it was not really dark on that road, for a light shone on our path. Whence came this strange glow? How puzzled we were. Certainly it was not from the sky. It almost seemed to rise up from the ground with a strange soft brightness, which I should like to show you in the same way if I could. On the road before us were broken bits of limestone, just such pieces as you have seen scattered on the gas-tar and ashes to make asphalte. I daresay you have watched men throw this limestone on the black stuff and roll it in, so as to give the asphalte that *speckled* appearance. Here, however, was a road not asphalted, but simply strewn over with these bits of limestone. All day long the sunbeams had been playing on this limestone. Some of the rays had danced about on the outside; some had gone a little further inside. Light had showered down upon it, so to speak, and set it quivering all over, making it very warm. Now that the sun was gone down, the limestone was generously sharing with us the richness which

had been bestowed upon it during the day. Very naturally we felt interested in this unexpected act of kindness, and we wanted to know if this course was usual, or if we had been especially favoured, and we learned that there were certain

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FIG. 131.—READING BY THE LIGHT OF THE ELATER. The insect is allowed to cling to the finger, which is passed along the page. A spot two inches in every direction is brilliantly illuminated by the little creature.

substances which act in this generous way, giving us back some of the treasured sunbeams.

I have here some fluor-spar from Derbyshire. A little girl brought it to school, when we were speaking about stones. I cannot place this in the sunshine from now until sunset. I must try to show you without waiting so long.

We will lower the black blind to make it dark as evening. Now I take this red-hot shovel and strew this coarsely-powdered spar over it. As the stone warms, you at once see the glowing light I spoke of. It would be quite a mistake to suppose that the spar was burning.

I now remove the fluor-spar from the shovel, and substitute some chalk which shall be heated in the same manner. You will see how the glow lasts, even if I shake some off the hot shovel on to this cold slate.

Now I shall try some well-dried flour in the same way. I shall also slightly *warm* this piece of saltpetre and this quinine on the paper. I once quite unintentionally produced a brilliant flash of light in the dark by merely holding my warm hand over the neck of a bottle of dry quinine. Here you recognise some Indian corn. Children are almost as fond of it as chickens are. I have had some finely ground and dried. I think you will see that we obtain even a better result with that. Here too is a bone which has been burnt to white ash in the fire. We will put that also on the shovel.

Have you ever seen any similar light to this before? Yes, you say, rightly, that it reminds you of the light produced by rubbing two pieces of loaf-sugar together in the dark, that simple experiment which surprised you so much at home. The grocers would tell you how beautifully their shops are lighted up, when they break the sugar. Two milk-stones (quartz) rubbed together give out red sparks. I chose the sugar as being more interesting to little folks.

Not only is this giving back of light shown in lifeless matter; there are above twenty plants which shine in the evening from the same cause. Most of these have red or orange-coloured flowers. Besides the sunflower, orange

lily, the double marigold of our gardens, the French marigold, and the African marigold,[1] the nasturtium and the geranium are very noticeable in this respect. Light may often be seen playing on the ears of wheat and the gills of some mushrooms, notably the red mushroom, which grows about the roots of the olive-trees of Italy. Just as the sun goes down a pale blue gleam flashes out suddenly from the gills. As night comes on the colour deepens and brightens and does not entirely fade until sunrise. If the mushroom be carried into a dark cellar, it glows with light for many days. Another (*Rhizomorpha*) of these flowerless plants lives under the bark of old trees. It looks something like a long, thin, dark-coloured root, and is also found in caves, as well as in our coal mines, where the miners are able to read by its pale white light. In the mines of North Germany the crevices in which this plant grows, appear like chinks through which moonlight is stealing.

But let us for a moment return to those examples which you may observe for yourselves. I refer especially to the geranium, the nasturtium, the poppy, and the marigold. Sparks and flashes of miniature lightning are seen darting from the petals of nasturtiums and marigolds, especially the latter, in the daylight. But the geranium flashes forth just at sunset, in a similar way to the red mushroom. Sunset then is the best time to watch the flowers of the geranium, after a hot sunshiny day. You will see—no, I shall not tell you what you will see—something that will surprise you.

Then pluck a green leaf from one of these plants—take a nasturtium leaf, for example, at this time, and carry it into

[1] "Among others may be mentioned Helianthus annuus, Lilium bulbiferum, Calendula officinalis, Tagetes patula, and Tagetes erecta." —*Brit. Ency.*

an almost dark room. What—you won't see it? Yes, you will see it by its own light; a kind of moonlight will spread itself over it. Take out your lens, your drop lens say, and look through it. You will observe a number of radiant points twinkling all over the leaf. Now fix your eye upon the centre. The veins branch out on all sides in the form of one bright star. Sometimes decayed wood is seen to be luminous. This is due to a little plant which grows upon it. You may have noticed the thread-like fibres.

Some animals, too, possess the power of giving out light; except in the case of earthworms, millepedes, centipedes, and moles, this can scarcely be called giving back the sunshine, for most of the animals have special organs for producing the light, which can be used at will. In many jelly-fishes the light is seen to be sent from all parts of the body. Most of the light-bearing animals belong to the sea. Millions of them light up the waves in certain parts of the ocean, or spread over the beach a sheet of fire. Humboldt bathed among the noctilucæ of the Pacific, and tells us that his body was luminous for hours after, and even the sands, on which the noctilucæ were left at low tide, appeared like grains of gold. Yet several insects have also this power. If you have never seen the fire-fly or the glow-worm, you have at least heard of the glow-worm's tiny spark, which "lights the traveller in the dark." The glow-worm of South America is even more brilliant than our own. There are over seventy kinds of beetles in South America. Glow-worms have two yellow lamps on the back and two others under their wing-cases, though these latter are only seen when the insect flies. It is merely necessary to hold one of these little creatures in the fingers above the letters in order to read the smallest print. If eight or ten of them be put

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FIG. 132.—EVENING DRESS. The Maid arranges a Coronet of Diamonds (*Tropical Fire-flies*).

into a bottle, the light from the little lamp is bright enough to write by.

This very beautiful insect may be found shining in the darkness as night is coming on, lighting up the dead damp wood and rotten leaves. If you take it up in your fingers you may fancy you have there a beautiful diamond ring. Some of these sparkling insects are worn by the ladies of Havana, fastened as ornaments to the dress on festive occasions. Others wear them in their hair. On more than one occasion these wandering sparks, seen in the darkness of the night, have made even our own brave soldiers imagine they were meeting an overwhelming force in the distance, and hastily turn back.

The lantern-fly has been wrongly included in this list. This fly is so called merely from the shape of its forehead, which is fancied by some to resemble a lantern; but it is a lantern *without light.*

Time would fail me to tell you of the tiny lights of the sea. One I must mention, however, called the Night-light,[1] one which lights up the water between here and France. It was among these that Humboldt bathed. It is a mere speck of jelly no larger than a pin's head. When very much magnified it looks like a peach with a long stalk, which it wags about and pushes against objects that come in its way. In its body are little points of light which appear and disappear very rapidly as you watch it. In some parts of the English Channel there are about 25,000 of these creatures in a cubic foot of sea-water. In the words of Victor Hugo: "The water seemed a-fire. As far as the eye could reach, among the reefs and beyond them, the sea ran with flame. The flame was not red; it had nothing in common with the grand living fires of volcanic craters or

[1] Noctiluca MILIARIS.

of great furnaces. There was no sparkling, no glare, no purple edges, no noise. Long trails of a pale tint simulated upon the water the folds of a winding-sheet. A trembling glow was spread over the waves. It was the *spectre* of a great fire rather than the fire itself. It was in some degree like the glow of unearthly flames lighting the inside of a sepulchre. A burning darkness. The night itself, dim, vast, and wide-diffused, was the fuel of that cold flame. It was a strange illumination, issuing out of blindness. The shadows even formed part of that phantom fire.

"The sailors of the Channel are familiar with these indescribable phosphorescences, full of warning to the navigator. By this light surrounding objects lose their reality. A spectral glimmer renders them, as it were, transparent. Rocks become no more than outlines. Cables of anchors look like iron bars heated to a white heat. The nets of the fishermen beneath the water seem webs of fire. The half of the oar above the waves is dark as ebony, the rest, in the sea, like silver. The drops from the blades, uplifted from the water, fall in starry showers upon the sea. Every boat leaves a furrow behind it like a comet's tail. The sailors, wet and luminous, seem like men in flames. If you plunge a hand in the water you withdraw it clothed in flame. The flame is dead and *is not felt.* Your arm becomes a fire-brand. You see the forms of things in the sea roll between the waves as in liquid fire. The foam twinkles. The fish are tongues of fire, or fragments of the forked lightning moving in the depths."

It is reported that the captain of an American vessel crossed a belt of sea nearly 30 miles broad in the Indian Ocean by the light given by myriads of sea-worms (30,000 in a cubic foot), which seemed like fiery serpents, and made the waves look like a sea of silver on which the vessel cast black

shadows. The creamy tint of parts of the opposite shore of the Atlantic is due to myriads of little shrimps. Crabs also have the power of emitting light, especially when disturbed or irritated, but in most cases it is not known from what part of the body the light proceeds. Some members of the crab family have small round orbs under the body which often have been spoken of as *eyes*, and indeed there seems some reason for this, as the globes contain many parts, one of which is a real eye-lens which, acting as a condenser, enables the animal to send forth a bright flash of light in any desired direction. Many deep-sea fishes too possess a similar luminous organ either near to the eye or along the sides of the body; some of these are eyes of a very simple character, others are chiefly supplied with a light and a globular condenser through which to send it. The fact that many of these deep-sea fishes possess large (real) eyes besides the light-producing arrangement, has led to the belief that this source of light is a sort of recompense, and of great benefit to them in the ocean depths, where no sunshine ever reaches.

I must just remind you before I close of those beautiful colours seen on fresh fish, such as herring, haddock, and mackerel. I daresay you know that these colours gradually fade, after the fish has been drawn from the sea. Were you to place these fishes in a dark cellar while fresh, you would see a glow of light play all over them. In some cases the light is so brilliant as to enable a photograph to be taken. A haddock has thus been photographed *by its own light.*

And now that our story is finished, can you answer my question: Who lights the lamps in the three kingdoms of Nature?

Home Experiments

75. Cleave mica in a dark room.

76. After a hot sunshiny day, examine (*a*) a geranium *at the moment of sunset*; (*b*) sparks and flashes from marigolds and nasturtiums, both before sunset and for an hour afterwards; (*c*) pluck a nasturtium leaf, carry it into an almost dark room, and look at its central point through a pocket lens.

77. (*a*) Blacken a card (in ink), make a slit ($\frac{1}{8}$ inch) in card, and rear it up in front of a distant candle. Look at it through a similar card with a slit in it, held at arm's length.

(*b*) Look at the edge of a distant flame, with the eyes almost closed.

CHAPTER XXXIV

THE MILL WITH STAINED-GLASS WINDOWS

I DARESAY you have wondered why I have seemed to take so little notice of the home experiments that you have been busy with lately. That I have said little, is quite true, and that you have been interested, delighted, and puzzled is equally true, and known to me all along.

To-day I shall try to make up for what may, to you, have seemed to be neglect, though really it was quite the opposite, for I wished you, first, to find out something for yourselves, and so, planned a number of very simple home experiments.

We shall need a very brilliant light, and for this purpose, we will make a hole in the blind where the sun will shine through. I must ask one of you, or perhaps two of you (to relieve each other), to go into the play-ground and reflect light into the room. We shall use the gas-globe filled with water, as a condenser, and for that purpose I make a round hole 4½ inches across, in the blind, and place the condenser in front; within the focus of the condenser I place my pocket-lens. Just within the focus of the pocket-lens this piece of ruby glass shall go. You see that the glass stands erect in this "bull-dog" clip. In front of the glass I draw up this black screen, in the centre of which is a slit 1 inch long and ⅛-inch wide).

This is the most difficult arrangement we have had yet, and I am sure you will agree that it is quite easy. It is merely the solar microscope, with the ruby pane added.

Tell me what you see before you now. "A little window," Herbert says. Mary says, "A long window." Whereabouts in the house do we find long windows? On the staircase, Fred tells us. Now I want you to look at that stained-glass window, through the slip of smoked glass which lies in front of each of you. The glass has been coated with "lamp-black" that we learned about. How? "By being held in the lamp-flame." Charlie is quite right.

Turn the glass slide over without soiling your fingers, and make a fine line, using pencil and ruler, as I do. Now take up the glass and, turning the smoked side towards me, look at the little window through the line you have made. What do you see, Herman? "Like a big house or school with a light in the middle of the room." What do you think it is like, Edith? "I think it is like a big mill, all windows; but they don't have red windows in mills."

Now I take away the red glass and exchange it for pure blue. You have a blue window. Look through your smoked glass and tell me if there is any other difference, Tom. Oh, yes, there are more blue windows in the mill, Isabella says, and they are longer. Are they? No! I think they are narrower, and that makes them look longer.

Now with a clip at the side, I fix this strip of pure blue above the red, so that the lower half of the window shall be red and the upper half blue. Now you are able to compare the windows in the first and second story. Look again through the scratch. Tell me which windows are larger—red or blue? Which are closer together—red or blue? Are the blue windows exactly over the red ones? No. Just let me look through some one's glass. Do you think

I could draw the mill on the blackboard. I will try. Now I am going to give you something to think about while you watch me.

Fancy that instead of two glasses in our window, we have seven colours, one above the other. At the bottom red, then orange, yellow, green, blue, indigo, and violet at the top. Do you see it? in your mind's eye, of course. We will think first of only two rows—red and green. My drawing is done. Is it like what you see through the glass? Yes. You know how to open the window as wide as possible,

FIG. 133.—"THE MILL WITH STAINED-GLASS WINDOWS." The red windows are broader and farther apart than the green ones, while the violet windows are narrower and closer together.

Tom? You would pull the top sash over the bottom one, so. I close it again. Look at the board. Let us pull the green windows down over the red. With my ruler I continue the line in dots. They don't quite cover the red ones. Here a bit of red is left uncovered, here is a bit of green, here is more red, and here is more green, while the brick space between the windows is growing less.

Now here is a strip of violet glass. I fix it above the green and make three rows of windows—red, green, and violet. Look through your smoked glass, and tell me what you think of it (Fig. 133). The violet windows are very

narrow indeed, and very close together. Are they *exactly* over the green ones? Suppose I slide the violet windows over the green, can you tell me what the result would be? Some violet edges would be left uncovered.

The same is true of all the colours, though I cannot show you each kind of glass; it would take too long, besides which —I haven't got them. The colours of the spectrum make narrower windows as they rise from red to violet. The orange windows are narrower and closer than the red, the yellow more so, green still more, the blue you see are very narrow, and so on to the violet, which are the narrowest of all. Now let us come back to our rainbow-window. What colour are the bottom panes? (red). The next row is what colour? (orange). I slide the orange ones over the red. Tell me the effect? There will be little uncovered strips of red and orange up and down. Now I draw down the sash of yellow panes, that will give us yellow strips uncovered as well, and the same with the other colours. In the rainbow-window we have been thinking about, we shall have edges of every colour; and since you have been so good as to think it out, you shall not go unrewarded! Tell me, why do we use stained glass for the windows? Is not the stained glass a kind of gatekeeper or turnstile-man, who will allow only certain colour-rays to come through his gate. I think we might do without him, don't you? Our window has panes of every colour, so we don't want to stop any colour-rays. We will send the gatekeeper off, and to represent our window with panes of all colours, *one behind the other*, we will use *all-coloured light.*

Look now through the smoked glass at the all-coloured window. Do you see the edges of the other windows? You do. They cover up the spaces, between the windows, where the brickwork was before. Will some one lend

me a smoked glass? Thank you! It seems to me that the white windows are neither so broad as the red ones, nor so narrow as the violet; neither are they so far apart as the red, or so close as the violet. The middle window is the brightest. It seems as though a large chandelier were hung in the centre of the building, and made that spot intensely bright. Don't you think the gases at the other ends of the building would do with lighting up?

Now take your glass slips and rule a very fine line this time with a pin or needle. Now, James, tell me exactly what difference you see on looking through the fine line. "The windows are broader now." Yes, the finer the line is, the wider the windows are; the thicker the line is, the narrower the windows are.

Now our time is very nearly up. Make a large pin-hole in the bit of black paper before you. Closing up the slit, I make a small round hole in the screen instead. Our target will do admirably. With the red glass behind it, you see through the pin-hole tiny circular windows with black bands round. Look now at the blue glass I hold here. We have smaller windows closer together. With all-coloured light, you see, we have white stars, as it were, with rainbow bands round. I think that even from what you have learned to-day, you will be better able to understand your home experiments.

Home Experiments

78. Repeat as many as you can of the experiments with coloured glasses.

79. Look at a point of light—close one eye, brush the eyelashes of the other with the finger. You will see fountains of fire.

CHAPTER XXXV

MOTHER-OF-PEARL

BEFORE you sit down to your story to-day, you shall pass by this screen and look at these shadows, then take your places quietly.

Our arrangement is the same as in the last, except that the condenser is placed higher up in the window, so that you may pass under, without casting your shadow on the screen, if careful.

I have pushed a knitting-needle into a cork and placed it at a distance of four inches from the screen and four or five yards from the lens. I want you to notice how very much larger than usual the shadow of the needle is, and that this shadow is bounded on each side by rainbow bands. The band nearest to the shadow is striped with violet, indigo, pale blue, green, yellow, and red; next is a band of blue, yellow, and red; and outside that again is another band of pale blue, pale yellow, and red. At the same distance from the screen is placed a fine hair. We have the same rainbow bands, but no dark shadow at all; its place is entirely taken up with the bright coloured fringes, but here the stripes are much narrower and closer than outside. Look carefully, and do not miss one.

At home you may try the experiment more fully if you

like. Newton made a pin-hole in a piece of lead. If your hole in the shutter is too large, close it up with some of this black paper or your little silvered disc with the hole in the centre. He tried the edges and backs of knives, also hairs, threads, pins, and straws, and many other things, and found that the shadow was much broader than when a large beam was admitted. Why?

Newton found out that the fringes were not due to the different materials of which the objects were made, for they were the same with metals, stones, glass, wood, or ice. Perhaps you may see in this some explanation of the won-

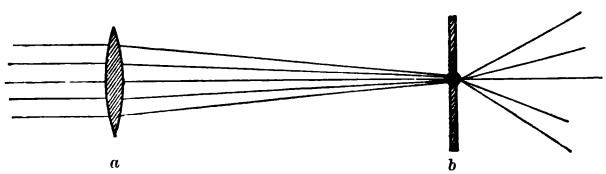

FIG. 134.—FRESNEL'S LENS. (*a*, Lens of short focus.) *b*, Fresnel's lens, a drop of glycerine.

derful effects with the black ribbon and the handkerchief, because every thread is edged like a coloured fringe.

I can show you the knife-edges experiment in a very simple way. A strip of tinfoil is fixed on a glass slip. With my sharp penknife, I make in the tinfoil a narrow slit running up to an extremely fine point. The edges of this slit represent the two knives. I fix the object about six inches in front of the screen and you are surprised to find, that the central line is *dark* and is surrounded by coloured fringes of most singular form. When you have looked at the screen pass on to your seats!

I have prepared a few objects for you to see, but first we must reduce our light to a *mere point*. We shall use the

condenser as before and a microscopic lens (with or without the pocket lens). With a drop of glycerine inserted in a hole in a metal screen (Fig. 134) Fresnel found out many wonderful things of this kind. We cannot do better than follow his example.

For this purpose I shall make use of one of our targets, covering the hole with tinfoil. I now heat the point of this hat-pin and make in the tinfoil a largish pin-hole, and insert with a feather a drop of glycerine. I move this lens into the focus of the other. The image of the sun formed in the focus of the drop lens is exceedingly brilliant. To make sure that no other light enters your eye than that which has passed through the lens, I will cover the solar microscope, for that is really what it is, with a box blackened inside; in lieu of a better I will use the lower part of our sunshine lantern after removing the lenses. I lay it horizontally on the table, with one short end towards the window. (*Focus first*, then place the lens aperture close up to the drop lens; the condenser will be somewhere inside the box, say near the middle.)

Here is an object which gave me a little trouble, but is well worth it. I fixed a dozen fine sewing needles close together in a piece of blackened wood, then withdrew half of them. You now see six needles, each separated by the distance of one needle (needles 2, 4, 6, 8, 10, 12 being withdrawn). I shall fix it up in the beams from our tiny sun. There is a small piece of finest copper-wire gauze on the desk in front of each of you. Take it up and look at the needles. What do you see, Donald? "I can see right through the needles." Then they are transparent?—do you observe anything else? "Yes, there is a delicate red line in the centre of each needle." That is very good!

The next you will find quite easy to make; it is merely

a slit ($\frac{1}{20}$-inch wide) made in tinfoil. Notice how much wider the slit appears. Do you see the two indigo lines down the centre, and the fringe of colour bands extending for half an inch on each side of the slit?

This is also very simple; it is merely a line of small holes in tinfoil, pasted on glass as before. It looks like a row of buttons. What do you make of that? There are rainbow fringes round each hole, Alfred says.

Here is another. Round the central hole are six others, equally distant from each other, arranged in a circle. "It's grand!" Yes, I have no doubt. Let me look through someone's gauze. Each opening shows nine coloured panes, and the tinfoil appears full of holes—the colour effects are so grand that I shall not attempt to describe them.

Discs of glass, covered with tinfoil, in which holes of various shapes are made, may be fixed in the wide end of a small telescope. Sir John Herschel found, on looking at single and double stars, the beautiful effects shown in Fig. 124. When the hole was round he saw the star, or stars, surrounded with coloured halos. With a triangular hole, he obtained six-rayed stars. The four-rayed stars, were obtained by a hole formed by six squares, having a common centre. Other forms were produced by combinations of triangles having equal sides. Make holes of whatever shape you please. You cannot go wrong!

Now take up the little squares of perforated card (dipped in dichroic ink and dried), on the desks before you. You know what they are generally used for, don't you? Book-markers, Tom says—I suppose he speaks for the girls.

I place a piece of cardboard with larger holes before the lens, so as to be brilliantly lighted up. Now look at it through your cards. What do you think of that? Turn your cards round.

You can try most of these experiments at home for father and mother—this last one by placing a candle behind the second card, or by holding it out at arm's length while you put the other close to the eyes. Here is a bit of extremely fine muslin or cambric (blackened). Arthur, look at the edge of the flame through that and tell us what you see. The others may look after the lesson is over.

I dust lycopodium from a fine handkerchief on to this pane of glass. The glass plate has had a little very weak gum water spilled on it, and almost rubbed off with a duster. After shaking the dust from a height I breathe on the pane. Look at that distant gas-flame through it, Harry; tell me what you see. You see a rainbow round it. Yes! I will put it here for you all to look through afterwards. If you ever should find yourself in an omnibus, tram-car, or railway train on a foggy night, don't forget to look through the window at the lamps you pass. They are well worth keeping the eyes fixed on, and watching for each lamp to come into view.

I think all of you have tried the experiment with the feather. Here are some fine feathers from the wings and tail of the partridge. These feathers our friend Charlie, who lives across the way, says you can have to keep. Some feathers, such as those from the pheasant or peacock, are even better. Charlie's father does not sell peacocks, you say. No, but many people have peacocks' feathers in their houses, and I daresay you may easily possess one, if you care to ask your friends. I like these little partridge feathers, because I first saw the wonderful sight through one of them. Put the delicate end quite close to the eye (where it joins the nose) and view the light. What is the cause of this appearance? A look at the feather will show us a number of very close parallel lines

or slits, through which we see. You could not rule lines so even and so close, neither could I. If you could rule your smoked glass so well you would see the same sight

FIG. 135.—SCALES OF BUTTERFLIES AND OTHER FLYING INSECTS (highly magnified). These tiny scales are found fixed in the wing by means of the quill shown at the end of each scale, and are arranged regularly in rows, which overlap like the tiles of a roof. Observe the fine *parallel lines*, in some cases crossed by equally fine lines, making a network of exceedingly small *squares or other forms* of the most exquisite regularity and delicacy.

exactly. Brighter still are the colours on the scales of butterflies, moths, etc. (Fig. 135), due to the same cause.

Here is a very pretty shell, a penknife handle, and a bright pearl button. I shall draw down the blind and show you how pretty they look with the reflected sunbeams

playing upon them. As I alter the reflection of the light, the colours change. Is it not pretty? Whence are all these lovely colours? Are they part of the shell itself? Think. "Yes."

Ah! Freddy, you are caught! your companions are smiling. Will you take the pearl in the cellar? You remember now the coloured papers, you say, but I don't think you are convinced that the colour is *never in the object* but always in the *sunshine*. In fact, the colour *is* sunshine and *nothing else*. How hard it is to undeceive ourselves! But why does this shell behave so, to sunlight, as to separate the colour-rays and then mix them up again in this strange way? Let us see.

"Mother-of-pearl" is found lining the inside of certain shells, especially those of the pearl oyster and pearl mussel. I have not a pearl oyster, but here is the common oyster-shell you know so well. See how pretty it is inside! The outside, too, has a story to tell. If it could speak, it would tell us how the oyster, by means of its mantle or outer skin, separated out the crystals of carbonate of lime dissolved in the sea-water which it drank, and placed them side by side to form this shell.[1] This round disc near the hinge would say, "I was the oyster's first garment. By and by I became too small for her, as your jackets do sometimes. I mean that she grew so fast that I no longer covered her. Then she put a flounce or frill on, from the inside, to lengthen me. Again I grew too little; still she did not cast me off. She put another neat little flounce below that. So she has gone on always adding these delicate flounces up to now, and I suppose she will keep on to the end."

There! what do you think of the oyster-shell's story?

[1] Carpenter.

Is it true? She spoke as if she were of finest muslin, but actually the shell is hard, and protects the oyster like a house. The door is always open when in the sea; although there is here a very strong door-spring to shut it, if required, which you will know if you have ever tried to open an oyster. But perhaps you do not know what a strong spring keeps it open—or that the oyster's eyes are ranged in a row round about the doorway!

However, it is not with the oyster, but the shell that we are dealing to-day. We want to find out if the story be true. How? Here is a shell which I have cut in two; let us look for the "flounces." See, here are the edges. What a number of flounces the busy oyster must have made. The shell looks something like a flaky biscuit, where we have cut it. How thin the layers are, almost like the leaves of a book.

The shell is principally made up of calcium carbonate, the same kind of stuff as chalk, but arranged differently. Although our lesson to-day is not about the substance of the shell, I thought you would be glad to see an old friend in a pretty dress! Calcium carbonate is made up of two things. Do you remember how we got chalk? By blowing into limewater, Edith says. That is rather rough, Mary, is it not? How would you do? "I should breathe into it." What would you breathe into it? "Carbon di-oxide." Carbon di-oxide is the gas that effervesces or boils up, when a bottle of ginger-beer or herb-beer is opened, and gives to it that *sharp* taste. I put a drop of acid (hydrochloric) on the shell. Do you see the effervescence? Yes! it "fizzes," Sam says. What else is there in chalk besides carbon di-oxide? Lime, you tell me, Eliza. I won't take up your time with showing that, but after the lesson you shall reak the shells up and each take a bit home. With the ngs, put it into the hottest part of the fire to drive off the

carbon di-oxide. Then you will have lime left, which you can slake, as the bricklayers do, by pouring cold water on. You will have the pleasure of seeing it "kick up a shinty" in the dish, as Donald describes the action.

All the pretty shells that you see in the shops have been polished. I can't just explain *how*, except that it is much harder work than rubbing with a cloth. In polishing, these thin layers become cut across, and their edges stand up, forming a series of very fine close lines, so fine and close, indeed, that we can't see them without the microscope (Fig. 136). Some of the light is reflected from the grooves and some from the ridges, and by this interference the colour-rays become separated.

FIG. 136.—MOTHER-OF-PEARL seen through a microscope, which magnifies 20,000 diameters. That means, that all these lines were seen in a bit of shell so tiny that it would take *almost four hundred million* such pieces to cover this circle. It means, too, that *the lines in the shell itself are twenty thousand times closer together* than those in the drawing.

But Harry says it may not be the lines at all that "do it," perhaps it may be the thin plates of shell. I am very pleased with you, Harry, and think that what you say ought to be taken into consideration. It seems quite reasonable, also, to suppose that the many edges form somewhat transparent prisms. In fact, it is not always easy to decide *how* the colour-rays are separated in different objects. Still I hope to be able to show you that most of the colour, if not all of it, in this case is due to the lines.

And this was found out by accident. Some mother-of-pearl had to be fixed with wax to an instrument. The wax showed the rainbow colours too! See, I use this black sealing-wax, as if to seal a letter, and then stamp the pearl down on to it as a seal. In doing so, I make grooves in the warm sealing-wax. There the lines are, just as if I had ruled them, and there are, too, the rainbow colours! "You could make pearl buttons in that way." Yes! but sealing-wax would hardly do for buttons, Teddy!

The gentleman who found it out — no, Nellie, it was Brewster, not Newton — tried isinglass, melted lead, and tin, and always found the rainbow colours.

Mr. Barton had a machine made to rule fine close lines on steel buttons. Barton's buttons shone and sparkled like diamonds, both in sunshine and in gaslight. What makes diamonds shine so? Willie asks. I cannot answer your question fully now, but I will just say, that they are so cut as to have a very great number of sides or faces, and the edges where two faces meet form a prism. That accounts for the colour-rays from them. The white light is reflected from the faces, and the coloured light shines through the corners; but glass cut in the same way does not sparkle as diamond, so that the *substance* also has to do with it, for most of its light is totally reflected within; but even this is not the whole secret. I am glad, Lucy, that you remembered how diamonds give back the sunshine. I suppose that, contrary to the usual practice, you would wear your diamonds in the sunshine, if you wished to appear more than usually brilliant in the evening.

Home Experiments

80. Try Newton's experiments with hairs, threads, straws, etc.

81. Take a piece of oyster-shell home and put it into the fire. When all the carbon di-oxide is driven off, lime is left. Put the lime in a little dish or tin and sprinkle water upon it. It will join itself to the water with great energy. There will be a great battle, and when it is over, a new substance, which you call "slaked lime," will be left behind, and not a drop of water will remain. By adding cold water to the pasty stuff, and allowing the lime to settle down again, you will obtain lime-water for breathing into, and for pouring into the bottle in which the candle has burned.

82. Take the impression of some iridescent (rainbow-coloured) object by stamping it on black sealing-wax.

CHAPTER XXXVI

A PEEP BEHIND THE SCENES

ONE of our early stories was about the Spectrum, that beautiful colour-band into which the sun's image was drawn out before Newton's enraptured eyes. We shared his feelings, as we looked upon our own screen nearly two hundred years after, and allowed our fancy to carry us to a Christmas gathering, full of merriment—a Coloured Family "at home." To-day I want you to go with me to the same scene; for, quick as your little eyes are, they were unable to follow the nimble movements of certain members of that family. At the other extreme of the long file were members so grave and sedate that you likewise overlooked them entirely. We will go back and try, at least, to see the *little folks.*

There are rays beyond the violet, which have even been called *invisible*, because it is so difficult to catch a glimpse of them, and yet we know that they are there, because we find traces of their handiwork at times. These fairies take ordinary photographs; but not those of "our own camera," because that screen (*the retina*) is not sensitive to their presence.

Some violet rays strike the retina *seven hundred and ty-nine millions of millions of times in a second*: these we

can just see. There are fairies which exceed this limit; doubtless they send messages, as we judge by what we see on photographic plates and in other ways of which I shall speak. Therefore we may picture the Brain—the master in his counting-house—as "putting them in his waste-paper basket"? I don't know about that Donald, I'm sure there is some good use made of them, but we do know that he does not forward them to us in the same manner as those of the fairies who are less frequent in their demands.

How then shall we make the presence of these elf-like rays evident to our dull senses? We must contrive to handicap them in some way, and so slow down their movements as to bring them within the limits of vision. "How?" Indeed, I do not know how to explain the matter simply to you, with your present knowledge; but I will give you an illustration of something similar, though not the same. We will suppose that you are away at the sea-side—ah! you all smile now, I believe there is nothing you enjoy so much, for your compositions are full of it. Well, you are very frisky; you scamper about the promenade first out in one direction, then back to your friends to show that you are not lost; off again in another direction, back to report yourself; then off again in some new direction, just as little dogs do. Am I not right? Now your parents go down some steps to the sands; you continue to scamper about, but *not so fast* as before. By and by you come to the sand-hills. At every footfall you take a deep plunge; you feel yourself sinking in the loose sand lower and lower, and it is with quite an effort that you pull your feet out again. You would like to put them on firm ground after the trouble, but down they go again! You feel that you must raise them, or the sand will bury you completely.

You will agree that however spirited you may feel, it is not possible to scamper over sand-hills.

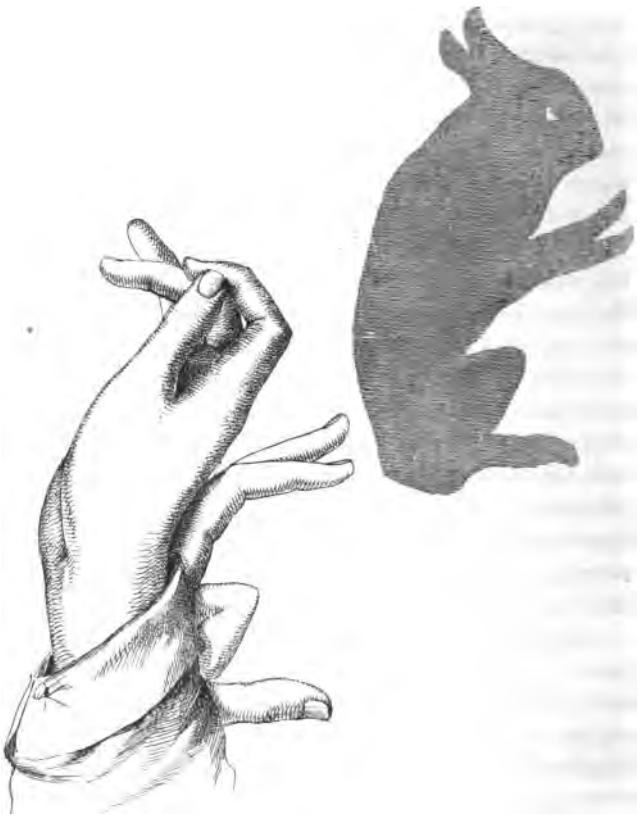

FIG. 137.—"BUNNY.

Now there are substances which act in something the same way with the colour-rays. Instead of allowing them to glint off the surface, or near it, as in ordinary reflection,

they cause them to plunge in to a greater depth and so *hinder them.* This is called *True internal dispersion,* because the colour-rays become dispersed and separated in the *interior of the substance.* Thanks to this hindering, I am able here and now to prove to you that there are colour-rays standing up beyond the violet, which marked the limit of Newton's spectrum. I could also prove to you the existence of the graver colour-rays extending beyond red, by *rousing them* to perform some wonderful feats for us, such as lighting paper, phosphorus, etc., or melting metals, but I must not. "Why?" Because of a rule which I have kept to, in my experiments, not to do anything which you may not try for yourselves at home. I should have to employ some very bad-smelling, dangerous stuff that would not be safe in your hands. Let us therefore proceed with the violet end. The paper you see in my hand has been prepared as a trap for the nimble fairies. I first dissolved some quinine in water by adding a drop or two of acid (*phosphoric or sulphuric*), and then having dipped in the paper in this *very strong solution,* I took it out, dried it, saturated it, and dried it again several times. It is now in prime condition to entrap the fairies.

After producing a pure spectrum as before, I take the quinine screen and fix it right across the ordinary screen so as to cover the lower half of each colour-band so that we may have the spectra, like two ribbons, side by side. There! that will do, but don't say anything yet! I can heighten the effect by placing this deep-blue (cobalt) glass —the same which you looked at the lamps through—against the slit. Now you perceive that the brightest colour-rays have gone; the blue glass has refused them admittance. In their absence, the violet shines with unusual brightness, and you would notice that the spectrum instantly lengthened

as they withdrew. If now we examine the quinine screen, the violet appears exceedingly brilliant, and a faint blue light shines right away for some distance beyond, where the upper screen has nothing corresponding to show.

Here is a paper washed with tincture of stramonium, prepared by steeping the seeds in methylated spirit. Without disturbing our arrangements in the least, I substitute the stramonium screen for our quinine. Here we have a very similar result — the blue reflection is replaced by a somewhat fuller light of emerald green, but I think it scarcely extends so far as the glow from the quinine did.

A third paper is painted over with tincture of turmeric: in this case we have an orange-yellow light which becomes more yellow as it extends. We see, too, considerable difference in the refraction of the upper and lower spectra.

Now I have shown you these three instances, in order that you may not run away with the idea, that the rays beyond the violet are either blue or green or yellow, as you might have concluded, if I had shown you but one. If you were to ask me "What colour comes next beyond violet?" I could not say, for my eyes refuse to tell me; we see *nothing* here under ordinary conditions. We never see these ghosts except in some altered guise. They present themselves blue, green, yellow, or other colour, according to the different substances we employ to entrap them *but never the same colour as the trap itself.*

And now that we have determined the *position* of these colour-rays in the spectrum, we shall proceed to other interesting points. Placing our violet glass against the window, and a lens of flint glass in the blind or shutter, we allow the diverging beam to cross this tall glass jar filled with water.

At home you should use a spectacle lens, if any, in the hole in the shutter; because ordinary glass stops most of the rays beyond the violet. Not having a lens of quartz I employ one of flint glass (otherwise I should use the horizontal beam *without a lens*). I pour in a little *weak* quinine. Ah, what is this? Has a bit of blue cloud dropped from

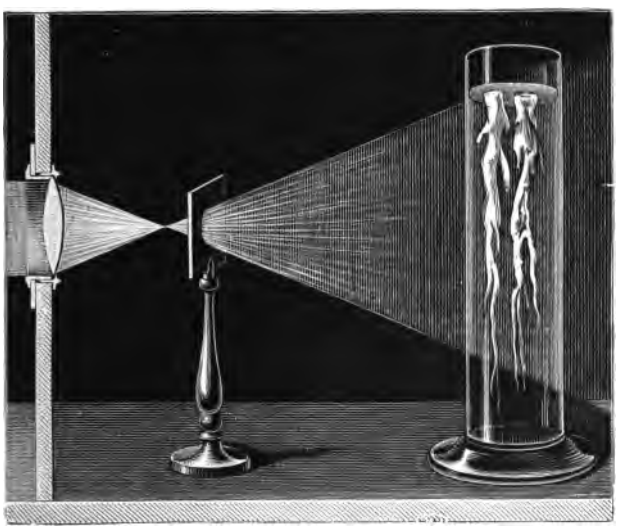

FIG. 138.—FLUORESCENCE OF HORSE-CHESTNUT BARK.

the sky into our water? No! that cannot be, for when I remove the blue glass, you observe that the so-called clouds are quite *transparent*: you can look at the things in the room through them. Let us have clean water, May. We will try again. This time I add a few drops of ammonia, and throw on to the water these two scraps of horse-chestnut bark. See how the cloudy streaks branch out as they descend (Fig. 138)! Here again the jar is lit up with

beautiful sky-blue light. This blue does not match any part of the blue band of the spectrum. As I look at it through this prism, I see that it is made up of several different colour-rays standing side by side. That tells a tale, does it not? Those transparent clouds descending from the bark have been *robbing the sunbeam* and are handing over their spoils to us.

The sunshine lantern is useful also in these experiments. Never be disheartened! If one mode of experiment be unavailable at the time, try some other. Placing the blue glass against the hole in the blind, we allow the beam to enter and pass through the lower basin, above which I hold a tube of weak quinine, closing it with my thumb. You see at once the pale-blue gleam shoot right across the tube. Now I pour a little into the lower basin and hold the tube above as before. The beam, robbed already by the quinine *in the basin* of those colour-rays which make up the blue light, passed through the quinine in the tube as through so much water. But if I exchange the quinine-tube for a bit of canary glass, held in the same place, it instantly glows all over with greenish-yellow light.

I will now show you yet another way of making these experiments. Here is a clay pipe. Round the outside of the bowl (shown in section, B, Fig. 139) I have wound a quantity of wick, such as we use in our spirit-lamp. I turn the pipe over into a saucer of methylated spirit, so as to thoroughly soak the wick, and afterwards I fill the bowl with magnesium powder. A long piece of indiarubber tubing is now attached to the pipe-lamp, for the magnesium light is too bright to have near the eye. This box is of about the same size as the sun-shine lantern, and is without a lid. We shall place its open side against that of the sunshine lantern, so, and burn the magnesium in this box; for the white powder (*magnesia*)

which falls would otherwise be driven like snow against the blue glass, and would stop the light. We shall need a hole near the bottom of the box through which to push our pipe stem. I take off the rubber tubing, push the stem through the hole *from the inside of the box*, and re-fix the tubing. Having seen that our sunshine lantern is right:

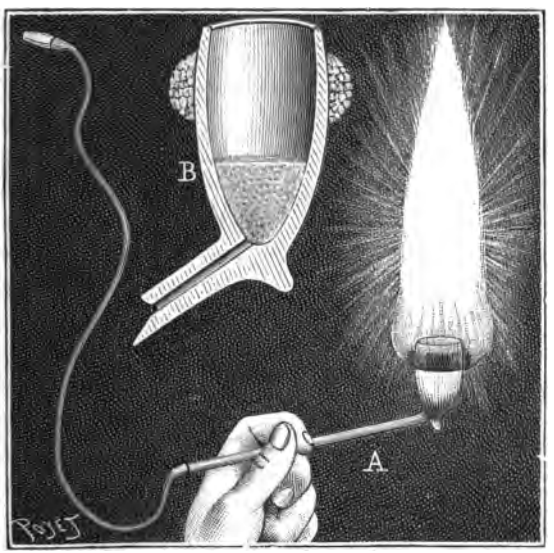

FIG. 139.—MAGNESIUM FLASH-LAMP.

the lenses being removed, the blue glass laid over the place of the condenser, and the mirror in position, I now set on the blue pane, glasses containing various liquids, then light the wick round my pipe, and taking the tube in my mouth blow the magnesium into the flame. You now see the characteristic colour which lights up the interior of each lamp!

Magnesium light is very rich in rays beyond the violet. So is the electric light. No doubt you have noticed how its distinctly blue tinge made the gas-lamps appear a decided yellow by contrast. With electric light, Professor Stokes produced a spectrum six or eight times as long as the ordinary one.

You are quite right, children, in saying that this giving back of the light reminds you of our experiments with fluor-spar and other substances in our "Lamplighter" story. Professor Stokes found that certain kinds of fluor-spar, especially a green variety (*chlorophane*), showed this peculiarity so well, that he named the strange unexpected glow, which lit up the spar, *Fluor-escence.*

You remember that when we heated the spar on the shovel, it continued to glow for some time after the source of heat was removed. In fluorescence, the glow continues only for a *very little while* after the exciting light is withdrawn. The light given out by some flowers—the geranium for example—is seen but for a moment; although nasturtiums and marigolds sometimes shine for almost an hour after sunset. (You will find your blue glass useful in examining some of the flowers.)

I shall now show you an experiment, and see if you recognise it. This reddish-yellow liquid (*fluorescein*) fluoresces a brilliant green. You remember when we went together to the Manchester Exhibition, we saw in the chemical section, a wonderful fountain which puzzled a great many people. The basin of the fountain was painted in black and white stripes. The fountain was of this liquid, and under the fountain, up to the water's edge, the black stripes appeared green. A black pencil held in the water also opeared green. We need not be surprised that the beauti- l light, which we see here, attracted so much attention.

In conclusion, I will show you a few fluorescent substances, which every one of you can get to make experiments with. The first is *soot* dissolved in methylated spirit. You observe the greenish-blue fluorescence. Probably you were not aware of the beauty of this substance.

Most lamp oils although yellow, fluoresce blue; you may detect the reflected light playing over the surface even in ordinary daylight. It is popularly known as the *bloom*, and is regarded as a test in purchasing these oils.

Another experiment, which you all can make, is with tea-leaves. Drain off all the tea until the water which runs out of the pot is *quite colourless*, then allow the leaves to steep a while in methylated spirit. I will show you the result. It will also serve to illustrate the fact, that other than the ultra-violet rays cause fluorescence in certain substances. I shall allow various coloured lights to fall upon it; and in order to ensure their purity, I shall pass a beam of sunlight through a prism, first removing the violet glass. This green liquid from the tea-leaves I hold first in the violet rays: it fluoresces brilliantly with blood-red light, and this continues as I pass it through the different coloured lights, even up to the red!

Another liquid quite within your reach is red ink. See what a charming effect a few drops in this jar of clean water makes!

Finally, replacing the violet glass, I plunge my eye into the beam, and I see around me a bluish shimmer. Come here, Harold, and try it. Why, children, Harold's eye glows like a hot cinder! You must come and try this yourselves, after our talk is over. The fluorescence of the eye is due to the presence in the cornea and the crystalline lens of a small quantity of some substance similar to quinine.

Home Experiments

83. (*a*) At home I should like you to hold in the sunbeam an alcoholic solution of soot, or of "leaf-green" (*chlorophyll*), obtained from tea-leaves, or a glass of water into which you will let fall a bit of horse-chestnut bark, or a few drops of red ink. (Stir the water with horse-chestnut twigs if you can't get the bark.)

83. (*b*) You may each take a bit of this fluor-spar home with you—take a bit of chalk too. Perhaps at home you may get some magnesia, note-paper (*very dry*), a bit of pure silk ribbon, and a lump of cane-sugar. Place all these objects in the sun for a *long* time. Then look at them through your cobalt glass, or take them into a dark room.

CHAPTER XXXVII

A PIN-HOLE PHOTOGRAPH

Now, dear children, our talks about "Sunshine," like all other good things, must come to an end—in fact, have come to an end already! But to-day I wanted to make quite certain that you had fully understood one or two points upon which mistakes are commonly made, and, thinking how I could best bring the matter home to you in a way that you could not possibly forget, I took a pin-hole photograph, which I will show you presently. In our story of the Magic Lantern I said something about the word "magic," which I hope you still remember. We hear less now about magic lanterns than we used. A gentleman said to me the other day, that there were *real magic lanterns*; but his lantern was not one of these, for only the children's lanterns were "*magic*." I don't know how he made this out, for the *principle* is the same in both; it is merely a question of size and better quality. Other people say, "No! it is not the lantern that is magic, it is the *lens*, and they begin forthwith to talk about "wonder-working lenses." If you have any idea of this kind, lurking in your mind, part with it to-day, and from this time forth give the fairy sunbeams due credit for the work they do for us.

You have all seen photographs at home, either fixed in a book called an "album," or hanging upon the walls. I have

FIG. 140.—PIN-HOLE PHOTOGRAPH of Harvard College Observatory (rear), taken at sunset (*without a lens*) by Professor W. H. Pickering. Exposure, six minutes. The photograph was taken from the roof of the cottage in the foreground. Observe that the slates on the roof and the wires, the smaller observatories with their fluted walls, the huts, and the objects in the distance also, are all *equally in focus*, owing to the absence of a lens; neither is there any *distortion*. The trees probably whispered the secret many times during the six minutes: every time they waved their heads the plate made a note of the fact.

no doubt you have spent much time in looking at these. I daresay you have noticed, too, what I am now going to speak about. A group shows this best. Here we have a number

of people photographed together. Some of them are "taken well," others are not at all flattered; probably they are not very proud of their photographs. Look at it again. The people in the middle are "very good," while those at the ends of each row and those at the back and front are smeared and blurred. Now, why is this? The photographer would tell you, they were "out of focus."

In the picture that you took in your drawing-book over the chair back, this was not the case; every part of the picture was "in focus," every object was truthfully represented. The only unfortunate thing about your photograph was that you could not carry it away. If you took away the screen, the picture vanished. My picture is of the same kind as yours, but I put a photographic plate as a screen for the rays to lay their images upon. I will show it to you presently, and tell you exactly how it was taken.

Before that, I want you to go back with me to our first story. We saw, that with a tiny hole we obtained a sharp image of the source of light. As we continued to make holes, we saw that every hole gave us a clear image of the source of light—each ray passed through and laid down its image in an orderly way, exactly opposite to the hole through which it came. It was not until we made the holes *too close* together that we had any blurring. Still there was no confusion. The rays did their duty, but we did not provide them with sufficient space to lay down the photographs side by side, and so they had sometimes to lay a photograph down on the edge of another: just as little folks writing in copybooks have to do, when too many are seated in one desk. Freddie's copybook must be in front of him, even though it cover part of Albert's on the right hand, and of Edgar's on the left. So when we allow a very great number of rays to come in, as we do at the window now

and always, except when the blind is down, the pictures are so laid over that they look more like a heap of Christmas cards than one picture.

"But," says the photographer, "I do not want a million images. I want only one image, but I must have it very bright." Now, brightness depends upon the *number of rays that light up the object.* Each ray, as we have seen, carries with it the coloured image of that point of the object from which it comes.

We have seen how the rays are bent out of their paths on passing from air into water. We saw, too, that glass acted in the same way. You remember, how the lines of print seemed to have moved either up or down on the page, when seen through glass, particularly if the glass were thick, and more so when the glass was not flat. It is this *refraction* that the photographer turns to account. He chooses a piece of glass, cut to such a shape as will so bend the rays passing through it, that they shall carry their images to the same spot on the screen and lay them exactly over each other.

But see, the sun is shining in; let us take our opportunity! You won't mind my going back to our first story; it is so very important. I shall vary the experiment somewhat. I make a hole with a needle in our black blind, and receive upon this ground-glass pane an image of the sun. Not far away, I make another hole, and obtain another image of the sun. You see the rays tracking their way through the dust of the room straight to the screen. Now, I shall show you how the lens will bend the rays from each of these images till they meet and form *one image* of the sun on the screen, *when I hold it in a particular place.* Look at the meeting of the rays when I burn the touch-paper. Do you see them? This image of the sun is brighter than the first. It is twice as bright

as our first image, because twice as much light has fallen on the screen from the two pin-holes as from the one. I make another hole. Now, we have three distinct images. The lens will blend these into one. See how much brighter our sun-image is now! It is now three times as bright as before. I make another hole. We have four images of the sun upon our screen. Gathering them up, so to speak, with the lens, we have instead, one image four times as bright as at first. Another hole gives us five separate images. The lens unites these five into one image, five times as bright. Oh, dear! our sun has gone behind a cloud. Look now what we have upon the screen. Why should you be surprised? You surely expected this! Now, we make only one picture, six times as bright. I think we fully understand that point.

You want to know why those people at the back of the group were not taken so well as those in the middle. Let us see. I think I can illustrate that by an incident which occurs in school sometimes. A little girl puts up her hand and says, "Please, teacher, I can't see what is on the blackboard." I move it a little, then a little boy in another part of the class says, "Now I can't see it at all." I move it a little in some other direction, and at last get it into such a position that most of you can see it fairly well, while *for a particular place* in the class it is just right. This is something like what the photographer professes to do. When his screen is in the right position to receive the images of the back row, he must move it a little further off to get the images of the next row correct, a little further away still for the next row, and so on. He cannot have his screen in half a dozen different places at once, can he? So he does as I do with the blackboard—puts it where it is best for most of you.

Placing the screen at the right distance from the lens is called *focussing*. This focussing has to be done *because the rays have been "turned aside" by the lens* (as our diagram on

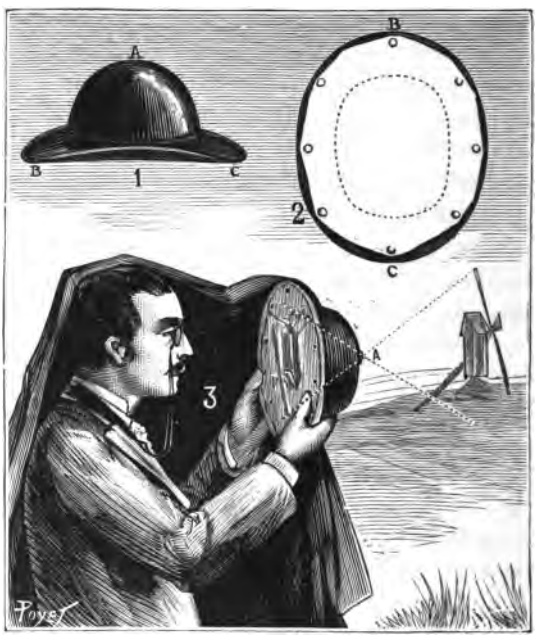

FIG. 141.—TAKING A PIN-HOLE PHOTOGRAPH. 1. *Shows an ordinary felt hat* A, B, C, having a ventilator at A. 2. *View of the base.* The leather lining has been pulled up over tissue-paper, and forms a border. 3. *Centering the object.* The hat is moved until a position is found in which the centre of the object occupies the centre of the screen. The photographic plate is then inserted.

the blackboard, Fig. 45, shows) and compelled to lay their images down at a particular place, a certain distance away.

That this is not so, when the rays are allowed to go about their own business, so to speak, I can very easily show you. The holes I used before are closed up. I make

another here, and hold the ground-glass screen very close to the blind. The image of the sun is very distinct; as I move the screen the image is still distinct, but weaker, and becomes weaker still, as the very little light, that comes through the pin-hole, has to spread itself over a larger and larger space.

I lent you a little telescope the other day. I think most of you had an opportunity of handling it. You only had the loan of it a short time, but I daresay you found out, that after looking at some near object quite distinctly, you must alter the length of the tube before you could see a distant object equally well. Yes, you say, you found that out. But Emily reminds me that we cannot see distinctly the gaspipe and the window at the same moment, even without any telescope. That is quite true. The eye is constantly altering its focus for us, with every new object that we look at. No, Harold, it is not done by drawing the retina closer or farther away, but by altering the shape of the crystalline lens, making it rounder for near objects, or flatter for distant objects. And the eye does this so quickly, and without inconvenience to us, that people, as a rule, know nothing about the arrangement, unless they have tested it for themselves as you have done.

Here is the pin-hole photograph. Shall I tell you how it was taken. Yes, you are very anxious to know, you say. It was taken inside an old felt hat. (Fig. 141.) I thought you would laugh at that. A small eyelet hole (A) was found in the crown. This hole was covered with tinfoil, and a hole was made in the tinfoil with a red-hot needle. A plate of glass, prepared in the ordinary way for photographs, was placed opposite to the hole, and behind the plate, a duster or cloth of some kind was stuffed in to keep out the light from behind. The plate was kept there

for twenty minutes: a much less time would have answered, *e.g.* five or six minutes with a special plate, but there is one advantage with an ordinary plate like this, that is, that people passing, leave no impression whatever, even though they stand near for a minute, and that is better than having a "blurred" image.

Home Experiment

84. Shortly before sunset, some afternoon, I should like you to try an experiment which has given me some very pretty diffraction figures. Move into such a position that you seem to catch the last little bit of the sun's disc in a corner of one of the window panes. Then half close the eye. Anytime in the afternoon will do, if the sun be not to bright to look at. It would be about 2.30 P.M. when I first tried it.

CHAPTER XXXVIII

PRACTICAL HINTS

Black Blind.—(*a*) This is made of slate-paper (blackboard substitute), to be obtained at the school stationers. The black side is towards the room, the white side next the glass. (The slate-substitutes inserted inside the covers of some exercise-books make excellent hand-screens; the material is the same.) Further, if the blackboard diagrams required for each chapter, as it proceeds, be drawn in chalk upon sheets of this paper, and these sheets remain fixed on the walls, they will serve as landmarks, which, by the time the course is ended, will form a useful series. The much admired Light diagrams adorning the walls of South Kensington Museum are executed in chalk on this paper.

(*b*) A blind may be made by joining two large sheets of stout brown paper, or even of

(*c*) Two or three widths of paper hanging.

If slate-paper be not used its substitute should be brushed over with paint or ink.

The blind should be much longer than the ordinary one, and wide enough to cover all the woodwork and enclose the recess of the window. It is suspended permanently from a roller in the ordinary way, and made to wind up and down

by cord and rack. It will not interfere with the ordinary blind because it is fixed higher. Let the bottom-rod or blind-stick extend beyond the ordinary blind. When the blind is *down* a pair of dumb-bells may be hung at each end of the rod to stretch the blind, and these lifted off before winding up.

Note.—It perhaps reads somewhat odd that the children should have by them what is asked for. In practice it is very simple. The stories are prepared beforehand, and whatever will be wanted is requested. In an assembly of 300 or 400 children, no difficulty is experienced in obtaining whatsoever is required, and many are the claimants for the honour.

Images of flame.—If the gas be inconveniently high use a candle. A halfpenny wax-candle (paraffine-wax) from the toy-shop answers remarkably well. The *best* result is obtained from a piece of glass tubing drawn out to a fine point. Take a piece of quill tubing about 5 inches long; heat in the gas-flame, constantly twirling in the fingers a portion of tube about 2 inches from the end. When quite soft, draw gently out a little way, re-heat and draw a little further, finally into a very fine thread, which severs. When quite cold, heat till softened a portion about $1\frac{1}{2}$ inch from the point, and bend at right angles. The tube is closed at the point; file off the extreme point—a scratch with the file is sufficient, then break off with the fingers. Unite the glass jet with rubber tubing to the gas-pipe; secure the joint with fine wire.

Pill-box camera.—Get a shallow pill-box of cardboard about 2 inches in diameter. Take off the lid. Blacken the inside to prevent internal reflection. The handiest way of doing this, is to fill with ink and pour the ink back again. Stretch a piece of tissue-paper over the top as a cover; gum

it on—in fact gum the surface as well. It then assumes the semi-transparency of ground glass.

Make also a number of small-size cameras for the children. When the bottom of the camera is "used up" replace it by the lid.

Holes in black blind.—Most of the experiments require a hole in the blind, 1 inch in diameter. The condenser requires a hole about 4½ inches in diameter. With a halfpenny held in front of the blind, a card held behind, and the use of a sharp pocket-knife, there is no difficulty in making the inch hole. Strips of the slate-paper gummed at the back, and circles of the same, 5 inches in diameter, should be at hand to close a hole, when no longer required. The condenser is not used for parallel rays, therefore it will be well to observe whether its use be mentioned.

Screens.—1. The very best screen procurable is a whitened ceiling. In schools where a class-room is set apart for these lessons it will "pay" if one wall, say that opposite to the window, is plastered, smoothed, and finished with whiting in the same way.

2. Next to this comes a smoothly whitewashed wall.

3. A sheet of paper, such as is used for large posters, may be had at the printers.

4. A map turned face to the wall will at once suggest itself—in fact, an old map not in use may be pasted over with paper, and this can be rolled up when not in use.

5. The hand-screens are described herein. These are used to receive small images, and are placed on the desk or table.

Coloured paper.—Squares (4 inches) of different colours are sold in packets at the school stationers. These are folded and cut into inch squares by the children, if required.

Management of the light.—The bright sunshine streaming

in at the window is sufficient for most experiments. Even without the help of the black blind, the spectrum is very brilliant when the prism is held in the hand. Choose a room where the sun shines in at the hour of lesson. It should have a southern aspect, though it need not be due south. A south room at 2 P.M. would do very well. The first hour in the afternoon has been found in practice to answer best for two reasons. First, 1.30 or 2 P.M. is better than 11 A.M., which would be the probable alternative. Second, there is opportunity and quiet afforded by the interval to arrange the apparatus and *to try the experiments, however simple.*

Simplex heliostat.—Where very brilliant light is needed, as in the later chapters, the light is sent through a sight-range by a boy outside (Fig. 6). The hole in the blind is one sight-vane. Another is in the school-yard. Each vane has a hole of the same diameter as that of the blind ($4\frac{1}{2}$ inches). The sight-vane in the playground may be fixed to an easel, reading-stand, or high stool, or may simply be a bit of white card fixed as a flag to a stick of any kind stuck in the ground. It should be opposite the hole in the blind, and preferably on the same level; then a horizontal beam can be sent into the room. The boy may steady his hand against something, but must keep his eye fixed, not on his mirror, but on the sunbeam, or he will find that he is not sending it through *both* holes; he will see that it gradually creeps off. Probably no experiment, if properly managed, will require his attendance outside for a much longer period than five minutes.

Mounting lenses and prisms.—Be not discouraged because your lenses and prisms are not mounted in stands like those we find in pictures. Newton was in the habit of using his fingers. The brightest spectra I have ever seen, have been

produced so. I admit that a stand is helpful. Take an empty bobbin, make a deep groove across the top, melt some sealing-wax in a spoon, and pour it round the prism or lens while you hold the same erect in the groove until set. Then remove the wax that is smeared, if any. It is a great mistake to suppose that experiments can only be made with particular appliances. Nature is too generous to make any such conditions. Far more frequently than you would guess, she has whispered some of her greatest secrets in the ear of some earnest worker, who used the things which lay nearest hand.

Heliograph.—The Morse alphabet is used.

THE MORSE ALPHABET.

A	– —	J	– — — —	S	– – –
B	— – – –	K	— – —	T	—
C	— – — –	L	– — – –	U	– – —
D	— – –	M	— —	V	– – – —
E	–	N	— –	W	– — —
F	– – — –	O	— — —	X	— – – —
G	— — –	P	– — — –	Y	— – — —
H	– – – –	Q	— — – —	Z	— — – –
I	– –	R	– — –		

Pure solar spectrum.—The spectrum will be brighter and clearer if a lens be used. Place it at a distance from the slit equal to twice its focal length, and the screen at the same distance beyond the lens. Then you will have on the screen an image of the slit, natural size. Now place near the lens, between it and the screen, the prism, with the edge you intend to use parallel to the slit.

To blend the "spread-out" colour-rays of the spectrum together again.—A confectioner's glass jar, such as we used for the sunshine lamp, is better than a globe. It should measure 6 inches across the top, and be filled with warm water. For a small spectrum, even a plain tumbler will answer the purpose, if its sides do not slope. *N.B.*—With the slit a cylindrical lens is used; with a round hole a globe or double convex lens.

Double convex lens.—The object to be distinctly magnified must be placed *between the lens and its focus*, not far from the latter (Fig. 50).

Burning glass.—Fill your penny bulb with turpentine. First suck out the water with a stem of grass; or you may put in, two or three threads of darning cotton or lamp-wick and leave long ends hanging out.

Ice flowers.—The ice must be cut parallel to the plane of freezing. This means, that you must cut it evenly, to the same depth all round, as you would cut a slice of bread —the top of the loaf corresponding, in this case, to the upper surface of the ice as it formed on the pond.

When first sawn, the surface will be too rough for the experiment. It will melt smooth, if you dip it in water for a moment. Don't be discouraged, if your figures are not so perfect as those in the picture.

You may use the solar microscope for this experiment, but as the object is not microscopic your lens should be larger than the pocket-lens. Nor is it necessary to use the condenser in this case, if you adopt the heliostat arrangement, *i.e.* reflect the light into the room from outside.

Heating red mercury oxide.—The flower-holder of white glass does nicely for this purpose, because the mercury collects in the bend of the tube, and also, because the bend keeps the tube from slipping, as a straight tube might do,

from hands not used to holding one. Use only as much powder as you can take up in the hollow of a pen. After all the oxygen has come off, and after you have looked well at the mirror formed on the tube, roll a piece of paper the width of the tube (inside), pass it into the tube and turn it round once or twice to gather up the mercury. Now carry the mer-

FIG. 142.—"PRETTY POLL."

cury gently over to a paper or slab and watch the drops roll about. People call it quicksilver. Quick is an old English word meaning "alive," as in the phrase "*quick* and dead." Notice, too, the spherical form of the drops (Fig. 74).

Slips and squares of glass.—A large pane of window-glass can be had for 1½d. It can easily be cut into strips or squares with a T square and a bit of quartz (Brazilian pebble), such as spectacle lenses are made from. Such a

fragment (costing 1½d.) I have used for years. The next best cutter is an emery knife "steel." The cheap glass-cutters have a steel wheel, which is useless after the first few trials.

Newton's rings.—After cutting the glass, draw the cut edges a few times across each other, as if sharpening a knife. There is no need to grind the edges if you do this.

Bubbles.—My mixture here is made in a slightly different way from yours. The soap used is made from olive oil, and can be bought *freshly made* from a good chemist's at 4d. to 6d. per oz. "Oleate of soda," it is called. This stoppered bottle holds 10 ounces of water. Fill it three-quarters full of distilled water, and put in 3 drams of oleate of soda. That is nearly a quarter of an ounce. Slice the soap very thin, and keep the bottle in a cold dark place. Next day if the soap is dissolved—if not, don't disturb it—almost fill the bottle with Price's glycerine, and shake well many times, then put back into the dark for a week. Then take it out very carefully without shaking, and find a scum or thick part at the top which you do not want, and clear liquid below which you do want. Take a syphon, *i.e.* a bent tube which reaches down to the bottom of the bottle inside, and lower still outside (baby's tube[1] will do if you don't forget to wash it well afterwards), and draw off the clear liquid into a bottle. Then you can wash the stoppered bottle perfectly clean and syphon[2] the liquid back. Keep it always closely stoppered, in a dark place. Let this be your stock bottle, which you visit only occasionally to fill a small bottle from. Never put any back into the stock bottle.

Mirror on stand.—For use with pocket microscope a

[1] Take off the end after starting it.

[2] The bottle that you wish to fill must be held lower than the other.

little mirror (2 inches diameter), in form like a loo-table, may be bought for a penny at the toy-shop. It may be fixed at any angle.

Touch-paper.—Most brown paper will smoulder. Touch-paper can be made by soaking thick paper—blotting-paper is best—in water with saltpetre dissolved in it.

The smoke reveals the track of the beam and makes the stories much more intelligible and interesting to the children, as well as affording an easy method of focussing.

Rings for bubbles.—Rings for home experiments may be made from rusty iron wire; or rust it afterwards, as Plateau did. They should be flat and circular. Test them round a halfpenny. If they be not perfect circles and neatly closed they will not work. Stands for these rings may be made thus:—

Stands for rings.—Take an empty bobbin, tear one ticket off, leave the bottom one on. Melt some sealing-wax in a spoon. Pour the wax down the hole. Let it set. Make a ring with a long handle. Hold the handle end in a flame till it is very hot (of course taking hold of the ring with a cloth). Fix the long stem *straight up* in the sealing-wax, and hold it steadily there till the wax cools. If you do *exactly* as stated you need not be afraid of its coming out. You can then bend the ring at right angles to make it horizontal. Take up both ring and stand in your hand when you dip the ring in the saucer of solution.

Orrery.—Take an indiarubber ball and paint in outline the continents upon it, so that you may recognise them. Place the ball on a watch-glass. Take an oval (nearly round) tray and draw a chalk line down the centre from one end to the other (Fig. 151). Place about an inch of wax-candle on this central line, near but not quite in the centre of the tray. (By first dropping some wax on the

spot the candle will stick to the tray.) Smear a little water on the path round the tray near the rim. Set the ball and watch-glass on it and gently tilt the tray. The watch-glass will revolve round the tray, illustrating Day and Night and the Seasons. If you have no tray, use a meat dish (inverted).

Cloud formation may be produced thus:—Boil a little Canada balsam in a flask. At the top of the flask, little globes of turpentine will be seen hovering about, altering in shape like the clouds of the sky. By thrusting a piece of cold glass tubing gradually into the flask these clouds will descend in showers.

A simpler way is to take the water-bottle and fit a cork and tube to it, so that you can suck the air out. First make the flask very clean inside and out, then rinse well with clear crystal water. When you have sucked the air out a cloud will appear. Hold your globe in the sunbeam admitted into a dark room, then you will see the cloud to perfection. Blow into the flask—the cloud disappears. In this way you may make the cloud appear and vanish as often as you wish.

Sundial.—How we spent our holiday (as told by Duncan to Charlie, who was not present).

First, Teacher told us that the sundial was the earliest measurer of time, and was common still among the Indians, Chinese, and all ancient peoples, and was regularly used in England until clocks and watches became so cheap. We still find them in country places and churchyards, and very pretty they look, and are useful too, as a check upon clocks. Then Teacher said—"You have noticed how the sun *seems* to move in an arch in the sky from east to west: the other half of this circle is too low down for us to see. If we lived at the North Pole it would be very easy to make a

sundial, for we should only need a circle equally divided like those old watch-faces which had twenty-four hours marked on them. A straight stick set up in the centre would always cast a shadow pointing to the hour, like the hand of a watch or clock. If you could place your left foot on the North Pole and trace out a circle with your right, you would then have the simplest of all dials, for your shadow, as you stood in the centre of the dial you had thus marked out, would point to the hours. But we do not live at the North Pole. The easiest way for us, that I can think of, would be to solder a stout wire to a plate of metal and bend the wire (at the base) until it pointed to the Pole-star. The North Pole of our earth always points to the North Pole star. Then our wire would have the same direction as the axis of the earth."

Hugh answered Teacher that the axis was a line passing through the earth from north to south, and that the ends of the line were called "poles." Teacher told Hughie that there was no *real* line, and that it was only imagined to be there to help us to measure; just as we put in a "guide line" down the centre of a vase, when we are drawing. She took out an orange and pushed a knitting-needle through for the axis, and then told us that it was not the end of the knitting-needle that represented the pole, but the orange itself where the needle had broken through the peel, and that the word "pole" meant "turning-point," and was quite a different word from pole, meaning "a stick."

"But as we do not live at the North Pole," Teacher said, "let us see from the map how far away we are." Then we looked out the latitude (distance from the equator), and we found that we live $53\frac{1}{2}$ degrees from the equator (or $36\frac{1}{2}$ degrees from the North Pole). At a place corresponding with this latitude, Teacher pushed a pin up to the head in

the peel at the edge to represent our town, and then cut the orange right across to show us what the circle of latitude meant. Now, we began to make our sundial after Teacher had explained to us that we should want three things—(1) the polar axis (pointing to the pole-star); (2) a vertical line (straight up and down); (3) a horizontal plane (flat level surface).

We set to work with our spades to make the piece of ground quite level, and a lot of the boys came running in for Teacher to come and look if it was right. Then Teacher said, "Can't you tell that yourselves? I will show you how you may test it. Our dial will be marked out on drawing-paper fastened to this drawing-board. Here, take the board, and when you have laid it so evenly that a marble will not roll off, I will come and tell you what to do next." We did that. Then we fixed up a straight stick vertically at the edge of the board, testing it if it were straight with the plumb-line (a string with something heavy at the end). We marked the end of the shadow of the stick on the ground, then we took a piece of string and held one end to the bottom of the stick and the other at the mark we had just made, and with the same length of string made part of a circle. Teacher told us that the shadow of the stick would grow shorter and shorter till twelve, and then would grow gradually longer and touch the same circle again soon before three, and we must watch then and mark the part.

It was a little after nine when we had done this.

Then we came inside and made the Gnomon, a triangle that should point to the North Pole. We took a square of cardboard, and from the corner (right angle) marked off 5 inches on one side and $6\frac{3}{4}$ inches on the other; then laid the ruler across from one mark to the other and

cut out the triangle with a sharp penknife. Teacher said the triangle was to be set up vertically on the dial; the 5-inch side was to rest on the meridian (line running north and south) when we had found it, and that anywhere on the meridian would do, but we must see that the apex (top part of triangle) pointed to the North Pole. After a while we went out to see if the shadow had grown long enough to touch the circle again, and when it had, we took a piece of twine and laid it over that part of the circle (circumference) between the two marks we had made, and cut the piece off. Then we halved the twine, and laid it down again over the circle, and made a mark where it came to. This halved the distance between our morning and afternoon marks, and this half-distance showed where the shadow would lie at noon. We joined this new point to our vertical stick by a line. This was our Meridian—the stick was at the south end of the line, the shadow at twelve due north. So we marked north and south, and drove a peg edgeway in the ground at north.

Teacher asked us if we would rather mark the dial to-day or wait till to-morrow; we wanted to do it then. So Teacher said, "I have made my watch correspond with 'sun-time' for to-day, and we can mark the hours and half-hours from that." James wanted to know if we could not halve the distance between the hours for the half-hours, but Teacher said that would not give them to us correctly, and so we marked it by her watch. It was not finished that day, for we had not the morning hours marked down.

Our dial now has the hours marked on, and looks very nice indeed, and we are going to have one cut in brass, since that we have learned how to make it. Teacher has shown us how to find "clock-time" by it. We were very much

puzzled at first, but now we can do it. We were shown on the blackboard, and I copied it down in a book.

Teacher said—"It is found that the days, as shown by a sundial, are not all of the same length, some being a little longer than others. It would be very difficult to make a clock or watch, that would go unevenly, to imitate the sundial. So we count our time by a clock which works regularly, and consider the time shown by the sundial (or by the sun, as we say) to be generally a little before or behind the clock. The difference between 'clock-time' and 'sun-time' for each day is to be found in the almanac. You will see a column headed 'clock before sun,' or 'clock after sun,' as the case may be. It is also called 'the equation of time,' for reducing apparent solar time (sun-time) to mean solar time ('clock-time' at Greenwich)."

If you buy a penny almanac for the purpose, look first if this is in. Every almanac should have it.

Teacher looked in the almanac opposite to the day of the month and found that the clock was 16 minutes "after sun"—that means 16 minutes behind, or slower than the dial. So we had to put our dial-time 16 minutes back for that day to make it correspond with the clock.

"If we lived at Greenwich our dial would be right when we had made our correction from the almanac." "But," said Teacher, "we do not live at Greenwich." "Just look how far from Greenwich this town is, Alec. Do you know how?" Then we had to find from the map (or from the index to the atlas) the longitude (or distance east or west of Greenwich), and Teacher wrote on the blackboard—

"1. We live 2 degrees 13 minutes west of Greenwich.

"2. The sun shines due south at 12 (noon) 'sun-time.' At that time the shadow of a stick set upright points due

north, and the line marked by the shadow is called the 'meridian.'

"3. The earth (in turning round) takes 4 minutes to travel over 1 degree.

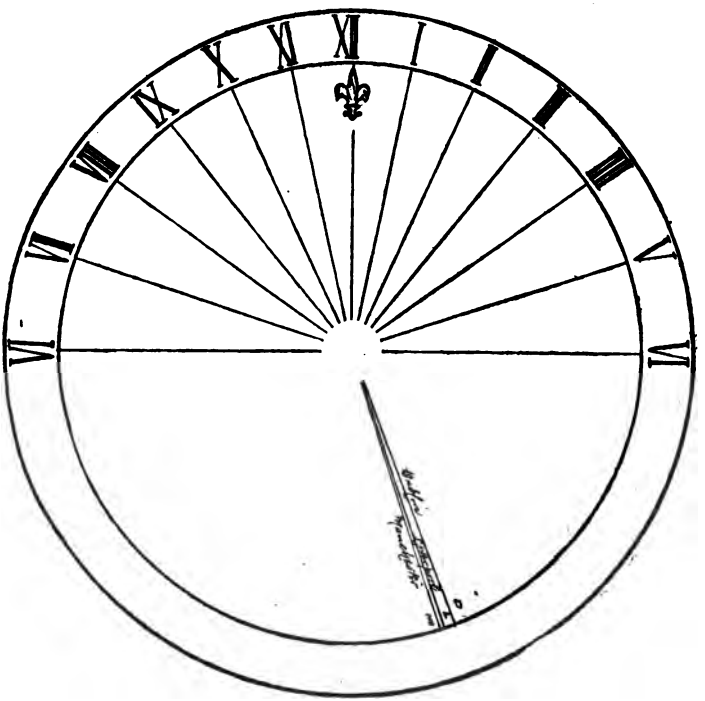

FIG. 143.—SUNDIAL FOR MANCHESTER, DUBLIN, OR LIVERPOOL (*and their immediate neighbourhoods*).

"4. Therefore the sun shines south *here* 8 minutes and 52 seconds after Greenwich. That means that when the sun is south (on the meridian) here, it is 8 minutes and 52 seconds past 12 by a sundial at Greenwich.

"5. If we knew the time by the dial at Greenwich we

could tell, without looking, what time our dial would point to, for ours is 8 minutes 52 seconds slow by Greenwich, and we should just have to take off so much time—*e.g.* at 12 Greenwich our dial would be 8 minutes and 52 seconds *to* 12.

"6. Our dial is *always* 8 minutes 52 seconds slow by Greenwich *whenever we look at it* (for the *distance* between here and Greenwich is always the same)."

Now let me see, Charlie, if you can tell clock-time from the dial in the playground?

1. If the clock is *before* the sun (faster than the sundial) you must *add* what the almanac says. If the clock is *after* the sun you must *subtract* what the almanac says. Then—

2. You must also *subtract* 8 minutes 52 seconds (if your longitude is 2 degrees 13 minutes west).

We asked Teacher how she knew "sun-time" before the dial was ready. She told us: "I went to the railway station. The clock there is kept at the same time as those in Greenwich. Then I found by the almanac that the clock was 16 minutes behind the sundial, so I must add 16 minutes. Then, as our time is slow by Greenwich, I must take off 8 minutes 52 seconds. Therefore I need only add 7 minutes 8 seconds to the Greenwich clock at the railway station to give me sundial time. I set my watch accordingly."

"Shall I put it on the board for you in case you want to mark a sundial? It is such an easy way—

	Hrs.	Mins.	Secs.
Greenwich time or railway time . . .	12	0	0
Clock behind sun (add)	0	16	0
According to almanac, the sundial at Greenwich shows	12	16	0
Difference in time, due to longitude (subtract) .	0	8	52
Sundial here will show	12	7	8

"For *this particular day*, then, our sundial *here* (long. 2° 13′ W.) will be 7 minutes 8 seconds faster than the station clock."

Drawing of dial.—The dial (Fig. 143) is drawn for Dublin, Manchester, and Liverpool. If you live in the same latitude you may trace over the lines, and afterwards mount your tracing paper on a large piece of cardboard and produce the lines. The larger the dial is, the more distinct and correct it will be. On a large dial you can mark also much smaller divisions of time. If you desire a dial which you can carry into any room, mount your dial on drawing-paper and fasten it down to a drawing-board. Place a mariners' compass on, or suspend a magnetised needle over the same, turning the board until the needle comes to rest upon the line naming the town in which you live. Your dial is then in the right position for the town named or its immediate neighbourhood.

ANGLES FOR CONSTRUCTING A HORIZONTAL DIAL

	Hours 11 and 1.	Hours 10 and 2.	Hours 9 and 3.	Hours 8 and 4.	Hours 7 and 5.	Hours 6 and 6.
						Always 90°
Inverness .	12° 44′	25° 28′	40° 9′	54° 36′	72° 22′	
Edinburgh .	12° 31′	25° 35′	39° 40′	54° 9′	72° 5′	
Newcastle .	12° 23′	25° 19′	39° 19′	54° 49′	71° 53′	
Birmingham	12°	24° 37′	38° 25′	53° 57′	71° 20′	
London .	11° 57′	24° 19′	38° 3′	53° 35′	71° 6′	

If you live at any of the above towns you can perhaps get some one to draw the dial from the angles I have calculated for you. These angles are each reckoned from the Meridian. If you cannot, then mark the dial from a watch set to sun-time.

In any case you will want the Gnomon.

One side (AB, Fig. 144) of the right angle you will make *five inches* long. The other side (BC) will vary according to the latitude of the place. I give the length in inches for a few towns, in order of latitude, from London to Inverness—

London, $6\frac{1}{4}$	Bradford (Yorks.),	Glasgow,	
Birmingham, $6\frac{1}{2}$	Leeds, $6\frac{7}{8}$	Edinburgh,	$7\frac{3}{8}$
Liverpool,	Hull,	Inverness, $7\frac{3}{4}$	
Dublin, $6\frac{3}{4}$	Belfast, 7		
Manchester,	Newcastle, $7\frac{1}{8}$		

Then join AC. *Your Gnomon is now complete.*

Let us look at it (Fig. 144), but do not mix up what I now say, with the directions given for making it. The base AB is 5 inches. For the side BC you have looked in the table. I have given this size as a convenient one for a portable sundial; but you will, of course, make your Gnomon correspond in size with the dial plate. If you make AB twice as long as this, you must make BC also twice as long. You may multiply AB by any number whatever, *provided that you also multiply BC by the same number.* This is why I have said 5 inches (or *units*). Let us now look at the angles. The angle at B is a right angle,—at C points to the North Pole,—at A is the same as the latitude of the place. Fix the Gnomon on the dial so that the point A hall rest on the centre and the point B on the Meridian, ar the crown.

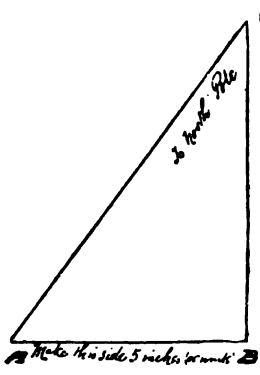

FIG. 144.—GNOMON for Manchester, Dublin, Liverpool (and other towns, *in the same latitude*).

I give also the time to be subtracted for difference of longitude. This never varies for the same town—

London, 12″	Bradford, 6′ 56″	Inverness, 16′ 52″
Hull, 1′	Birmingham, 7′ 24″	Glasgow, 17′ 4″
Leeds, 6′	Liverpool, 11′ 30″	Belfast, 23′ 44″
Newcastle, 6′ 28″	Edinburgh, 12′ 44″	Dublin, 25′ 4″

This is read: London, twelve seconds; Hull, one minute; Leeds, six minutes, etc.

Stereoscope.—This may be made either from a cigar-box or one of the neat mortised boxes in which the round chalk is "put up." You will want, besides, an oblong mirror, such as you can buy for a penny (or if you can afford it, buy better glass). Poor silvered glass *shines* like a piece of tin; a good mirror should look as black as ink. Measure the length of the mirror, and cut it in two at the half—or buy two mirrors exactly alike, that will be easier for you. You will also need two bulldog letter-clips at a penny each, and a piece of slate-frame having a *sound* corner. Take off the two long sides of the cigar-box, loosening them very gently so as not to weaken the joints that remain. Measure (with twine) the distance from one short side (end) to the other, halve the string, and draw a division line parallel with the ends, on the floor of the box. Now take the slate-frame and mark off on each side of the corner a distance equal to the length of one of your mirrors. Lay the ruler across the corner from one mark to the other, and draw the line where it touches the frame. Now saw off along the ruled marks. Look what you have—a corner (right angle) joining two equal sides. You see the groove which has held the slate? The opposite side is rounded. Probably it will require flattening a little. Rub it on a piece of sand-paper. Be sure that the groove is exactly uppermost as you rub.

This you can tell also by keeping your eye fixed on the other leg, which must *be vertical.* Now fix the angle on the floor of the box by sprigs, or the little headless tacks used for picture-frames. Look behind a picture; you will see then what I mean.

Now put your corner of slate-frame, as represented in the picture (Fig. 145), so that the line, showing where the two sides are joined to form the corner, rests on the line you made on the floor of the box. Take the mirrors out of their frames (if they are framed), and rear them straight up against the sides of the triangle (M, M'), fixing them carefully with sprigs. Your stereoscope is now finished, and will look like Fig. 146. Do not mind about the fancy ornament in front; it is merely a division to make sure that you will look in both

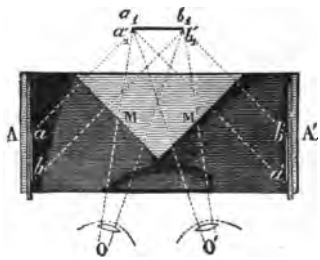

FIG. 145.—WHEATSTONE'S STEREOSCOPE (construction).

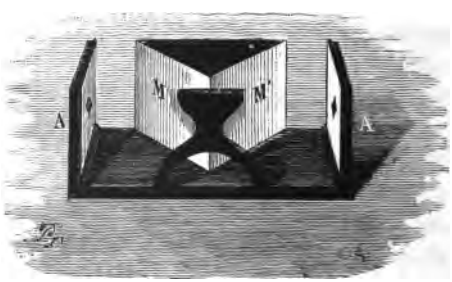

FIG. 146.—WHEATSTONE'S STEREOSCOPE (finished).

mirrors. A piece of black card fixed along the line on the "floor" of the box as far as the mirrors will do equally well.

Fix the bottom of each picture in a bull-dog clip. Place them in the stereoscope against the sides A, A', and regulate them. Each eye looks into its own mirror. One distinct image is seen *in relief*—that means the objects stand out as if "solid." If the clip is not steady turn its toes out. The position of the eyes is represented at *o* and *o'* in Fig. 145.

Note.—A simpler form of stereoscope is given in the Home Experiments.

Kaleidoscope.—This is made from two tin canisters (*e.g.* pound coffee canisters). One of these must be very bright. Turn the canister upside down, and with a tin-opener or sardine-knife cut the bottom out, leaving a rim of $\frac{1}{8}$ inch all round. Now take the *lid* in your hand and imagine you are going to draw a clock-face on it. Sit down where you can see the clock, and first put a mark where XII should go, now look for IIII and mark its place, also the place of VIII. Now taking up the ruler scratch lines from the XII mark to the IIII, and from the IIII to the VIII, and from the VIII to the XII. (You don't need to put the *figures*, only show their position.) If you have drawn correctly these lines should be equal to each other. Take a piece of stiff paper, note-paper will do, and measure one of these lines on its side; make a mark, double the distance by a fold, now fold the opposite way, and you will have made three spaces each equal to the first. Cut off the rest of the paper; you don't want it. The paper should show two distinct folds; if that is so bring the ends together and you will have a hollow prism Δ. Push this down the canister. If you have folded the paper correctly it should just fit without either slipping about or bending the sides of the triangle, which must be *perfectly straight.* If you are satisfied that this is so, you may cut out a piece of tin like it. I

suggested the other canister in case you had no tin-plate. Then you will measure the shorter side, and make it correspond in length with the triangular end of your paper prism. You will have a little piece to cut off. The other

FIG. 147.—KALEIDOSCOPE means *an instrument for seeing forms of beauty.* This design was seen on looking into one. Pieces of coloured glass are placed at one end of a long tube, with just room enough to slide into new positions as we turn the tube. Look at the *white triangle* in the centre of the figure. The black marks upon it show where the *bits of glass* happened to rest when the drawing was made. The other marks like them, on the *shaded* portion, are *images* of the *real glass*, seen in the mirrors which go from end to end of the tube. If you turn the tube ever so little, you have a new design.

side is right if the two canisters be equal in height. Now fold the tin-plate as you did the paper, and push it down the canister and see if it be right. Now find the disc you ·ıt out of the bottom of the canister; lay it on a sheet glass, and cut round the edge, not very close, so that

the glass disc is a little larger than the tin. Cut two of these. Gum one of them, and lay the gummed side on white tissue-paper, pressing out the air-bubbles. When the paper is quite dry cut round. The disc should now look like ground glass. If not clear enough, gum over the upper side of the tissue-paper (as in the pill-box camera). When your disc is quite dry, push it to the bottom of the canister and set the canister upright. Then take some little bits of coloured glass, half a dozen or so, and a few of the smallest beads. On top of these place *a little sideways* the clear glass disc, beautifully clean, and push in gently the tin prism. It must scarcely touch the glass disc. Now draw lines across the lid from XII to VI, and from IX to III, or from IIII to X. Draw two or three such lines. These will cross in the centre. Lay the lid on the table (with the hollow to the table), and make a hole, about as large as a lentil, in it. Put the lid gently on the canister or "tube," as we will call it now, and your kaleidoscope is complete. Take it to the window and look through the hole that you have made. Turn the tube round while you look through the hole; the pictures will change (Fig. 147). You might paint the tube outside if you can. Of course this is a very rough instrument, but it will do for a first attempt. By and by you will want something better, and you will use strips of silvered glass, or even of window-glass coated with black varnish, instead of the tin-plate. I have not told you anything about the *principle* of the kaleidoscope, but I will show you how to find that out for yourselves.

Principle of the Kaleidoscope.—Get two penny mirrors, or one cut in two. Take a strip of cloth or wash-leather for a hinge, and glue the short sides of the mirror down to it, side by side, so that they will open and shut like a book. If you place the mirrors at right angles you will see three images

and the object (Fig. 148). The smaller you make the opening between the mirrors, the more images you will see. The wider you open your book-mirror, the fewer images you will see. How wide the opening is, is shown in degrees. Now there are 360 degrees in a circle. The number of images including the object you can find out by dividing

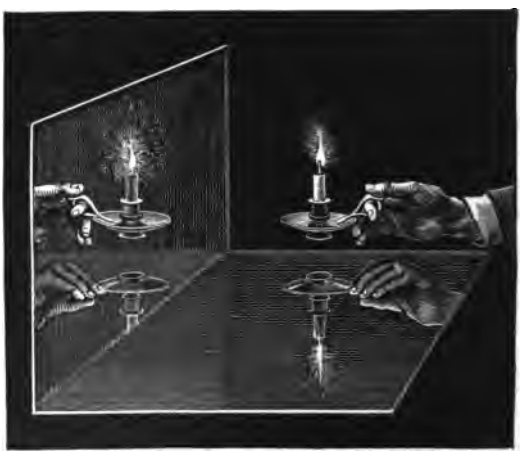

FIG. 148.—KALEIDOSCOPIC EFFECT. Images of a candle held between mirrors at right angles (90°), or between a horizontal and a vertical mirror.

360 by the angle between the mirrors, *e.g.* $^{90)}\frac{360}{4}$ (Fig. 148); $^{60)}\frac{360}{6}$ (Fig. 149); $^{45)}\frac{360}{8}$ (Fig. 150).

Now that you have tried the candle, try a key, a pencil, a flower, or a leaf. You can have endless amusement. Lay a bit of printed paper down between the mirrors.

The Frontispiece represents a kaleidoscope on the same principle as your own, but large enough for human figures. Like yours, too, it consists of three mirrors arranged in the form of an equilateral triangle. Two gentlemen and a

lady have stepped inside a triangular room with mirrored walls at the Paris Exhibition. Two mirrors only are shown in the picture: the mirror in the foreground having been removed, let us suppose that its images have become fixed, and that our artist has been able to sketch them; then we have the effect shown in the frontispiece.

Lenses.—These were made from Canada balsam heated and dropped on glass.

These are wanted for your pill-box camera, your model eye, etc. Don't be afraid of making mistakes. If you try, try, try again, you will be successful at last.

How we reckon angles.—I did not intend to say a word in these stories about reckoning angles, but as the subject is very simple and so useful that we can neither understand the sundial nor kaleidoscope without it, I will try to explain very briefly, what you might spend hours in hunting up. Angles are used to measure the amount of "turning." Take, for example, the turning round of the earth or of the moon, or of the hand of a clock, or even of yourself when you play at "ring"; or when you marked out with your foot the imaginary dial upon the North Pole. Turning once completely round, so that you face the same point as you did at starting, is called turning through an angle of 360 degrees. Turning twice round, is called turning through an angle of $2 \times 360 = 720$ degrees. Turning

FIG. 149.—Images of a candle placed between the mirrors when open at angle of 60°.

three times round, is called turning through an angle of $3 \times 360 = 1080$ degrees. I wonder through how many degrees you could make a top spin without its going down? How many degrees does the earth turn every day? (360). In a week? ($7 \times 360 = 2520$). How many degrees does the minute-hand of a clock pass through in one hour? (360).

Now I will puzzle you! Which turns round oftener in a day—the minute-hand of the Town-Hall clock or the minute-hand of a little watch the size of a halfpenny?

You remember that, in the knife-turning experiment, our beam of light turned round just twice as fast as its mirror, the knife. While the knife turned 360 degrees or once round, the beam turned twice round, or twice 360 degrees. How far had the knife turned when the light had gone right round the room? "Half round." How much is that in degrees? (Divide 360 by $2 = 180$ degrees.) The hour-hand moves more slowly than the minute-hand—it only goes round once in half a day. *The minute-hand goes just twelve times as fast.* While the hour-hand turns round once, how many degrees has the minute-hand passed through?

Here is the "clock-face" out of the Infants' School. I will see if you have understood me. Angles are measured not by the *size of the circle* marked out, but *by the amount of turning.* The hands of the little watch turn round as often in the day as those on the great dial of the Town Hall clock (or the time would not be the same).

Circles, whatever their size may be, are divided into just 360 degrees, though we don't generally mark the degrees down, unless we want to measure very accurately. You see the clock has hours and minutes marked. There are 60 minutes marked on this clock-face, and the same on the dial f my watch. We don't *generally* need to know the time

more particularly than this, though some watches mark even *seconds*. Those are very small divisions (ten times as small as degrees). If we divided each of these minute spaces into six parts, they would stand for degrees. We will not trouble to do so, but we will multiply the minutes by six instead. Now look! I set the hour-hand at XII and leave it there. You can manage the "times round" easily.

Now let me see if you follow me while I take the minute-hand slowly round. This time I shall stop at each figure, and ask you through how many degrees we have turned since we left the other hand, which still stands at XII. (You can either multiply the figures by 30 or the *minutes they stand for by* 6, thus figure $I \times 30 = 30$, or I stands for 5 min., $5 \times 6 = 30$.) Are you ready? "30, 60 (III stands for 15 min., $15 \times 6 = 90$, or $III \times 30 = 90$), 120, 150, 180, 210, 240, 270, 300, 330, 360." Half round? $\left(\frac{360}{180}^{2}\right)$. Quarter round? $\left(\frac{360}{90}^{4}\right)$. Ask yourself these questions, experimenting with the clock-face at the same time. How many degrees does the angle between the hands contain at 4 o'clock?—6?—3?—7?—9?—11?—8?—2?—5?—10 o'clock?

When the hands are just five minutes apart *anywhere* on the dial, the angle enclosed is 30°. The angular space enclosed when the hands are a quarter of an hour distant is 90°, half an hour 180°. Notice that this is a straight line, and yet we call it an angle containing 180°.

Show me angles of 45°, 120°, 330°, 180°. Now try to do the same on the other side of XII; make the hand turn the opposite way. At 10 o'clock tell me the two angles marked out by the hands? The great angle *forwards* is? (X multiplied by $30 = 300$, *i.e.* the hour-hand has travelled 300°.) The little angle between X and XII is 60°. Add

these together, $300° + 60° = 360°$. However many angles we divide a circle into, they always make 360° when added together. Don't you think this is a very interesting puzzle? When you look what time it is, measure the angles too, then they will become as familiar to you as the words in your reading-book.

FIG. 150.—Images of a candle placed between mirrors at 45°.

Here is another puzzle for you. Earth turns round once every day: how many degrees is that? How many degrees does she turn in half a day?—in a quarter of a day (6 hours)?—in three hours?—in one hour?—in half an hour?—in a quarter of an hour (15 minutes)?—in five minutes (one-third of the last answer, since $15 \div 3 = 5$)?—in one minute (this is one-fifth of five minutes)? You will find the answer to this last question in the sun-dial statements on the blackboard.

Note.—Should you desire further information on practical matters, look in the Appendix.

CHAPTER XXXIX

TOMMY'S DREAM—PART I

[THIS morning, on ringing the school bell at the usual time, there was no response—not a child was to be seen anywhere. I ventured further out, and found in a far-away corner a curious sight, a group of children intently listening with wide-open eyes to our young friend, Tommy Smith.

Naturally I felt very much surprised. Had the story-teller been a girl, I should not have wondered so much, but Tommy Smith, a red-haired, good-natured, gentle little fellow, slow and deliberate in speech, to be holding an audience spell-bound was a sight worth going far to see!

In another minute the children were in school. It was arranged that I was to have the pleasure of hearing Tommy's wonderful story myself, on the earliest suitable opportunity. On learning that Tommy had been favoured by an interview with His Imperial Majesty, King Sol, somewhere within the precincts of Dreamland, I gave him permission to relate his experiences to his classmates at the "Sunshine" hour.]

I had often looked on the face of the sun, and thought he was looking at me and nobody else, and I always smiled

back again. But this time he seemed so very near and smiled so sweetly straight into my eyes that I couldn't help saying, half aloud to myself: "Good morning, Mr. Sun, I was just thinking about you, sir. Don't you know me—I'm Tommy Smith."

"Nonsense! Tommy Smith is fast asleep! Look over there (*pointing*)! Don't you see him? You may look, though I may not, or he'll wake up, and I'm not prepared for Tommy yet."

[Sure enough there was Tommy Smith fast asleep in bed, just where the sun had pointed out.]

"Do you know Tommy Smith? Do you like him?"

"I know *all* Earth's children. I rather like Tommy, because he likes me; but I was not pleased with him yesterday, for he was gazing at me instead of doing his sums, and I distinctly heard his teacher say that he must be able to work very hard sums correctly, if he would know all about me."

"Perhaps he was thinking all sorts of kind things about you, though, while he was doing his sums."

"Doubtless! But that sum was not right, for I looked on his slate and saw a nine instead of a seven. You know I can do sums. I wouldn't have minded helping Tom if he had been attentive. But I must be off on my rounds, and see what my family is about. I've other worlds to look after besides Earth, and must not stand idle for a moment. Good morning, my little friend!"

"Oh, sir, couldn't you stay just a minute? I wanted to ask you such a lot of things, and perhaps I shall never see you again, to speak to. It's so good of you to talk to a little boy like me."

The sun smiled, and seemed very much amused. He aid to me:—

"No! I can't stay. I'll take you with me; that's the best I can do for you; then you can see me at work."

"I'd like to go, but shan't I be roasted alive?"

"If you obey orders I will take care of you. Now, Sonnie, what is it that you wish to know?"

"Please tell me first what you mean by 'going on your rounds.' I thought your family went round you?"

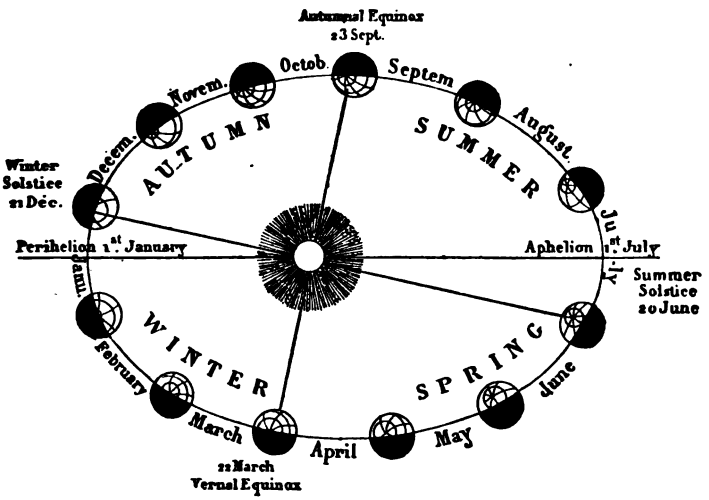

FIG. 151.—THE JOURNEY OF EARTH ROUND THE SUN. Notice her position on the 1st of January, also on the 1st of July.

"So they do. But a good master must himself go round also and see what is going on. I do not rise up from my place, 'tis true; that would mean instant destruction and death to my family."

"Where are you now, please? Are you not just beside me? I can see you so plain."

"I was looking at you when your teacher told you that

I was 93,000,000 of miles away. 'Sometimes a little nearer, sometimes a little farther,' did she not say?"

"Please, sir, are you just 93,000,000 of miles away now?"

"That is my distance at the beginning of October. On the first day of the hot month of July, Earth is farthest away from me. When winter comes round she rushes homewards at a terrible rate, until, on New Year's Day, she draws so close to her father, that he trembles for her safety, and dare only glance at her *sideways*."

"Why, how's that? *We* don't tremble. We're having jolly fun then!"

"Earth is 3,000,000 miles nearer me at that time than she is in July."

"Would it hurt us to come near you? You wouldn't do us any harm? I'm sure you wouldn't."

"Well, you see, it is this way with my family of worlds—they come right round here once every year—in fact, they each measure out their own year by the time required for their journey round me. You know how long Earth's year is? Little Mercury goes round in less than a quarter the time; but then he hasn't nearly so far to go, while some worlds are much farther away from me than Earth is (Fig. 118). Jupiter requires 12 of your years, Saturn 29, Uranus 84, and Neptune 165; so that one of your poor old men of eighty-five would now be a baby just turned a year old, if it were possible for him to have lived on Uranus instead."

"Do you have all the little worlds nearest to you and the big ones farthest off?"

"No, not altogether, though the smallest four are nearer than the others. Merry little Mercury, being the youngest, needs my closest attention, so I have him next me; but the largest world is Jupiter, and there is only little

Mars between yourselves and him. Then comes Saturn, the next largest, and the other two beyond are much smaller."

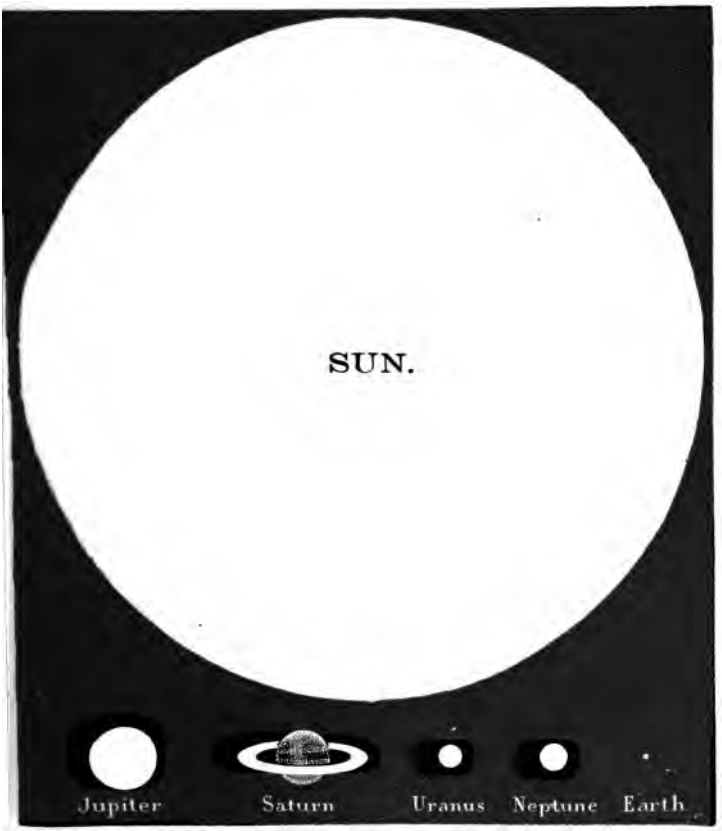

FIG. 152.—THE LARGER PLANETS COMPARED WITH THE SUN (*refer also to Fig.* 118).

"But I don't see why some of them should always be such a great way off and others always quite close; it doesn't seem fair."

"I said they were perfectly free to go all round me once a year, to waltz round, if they like — even earth's little moon does so; but each child must go at a particular rate and distance, or we should have collisions and accidents like you have upon your railways, although the times and paths of your trains are set down in time-tables."

"What sort of accidents should we have?"

"Well, you earth-children, for example, are formed to live at a certain distance away from me. If Earth brought you a little nearer than she does in winter, you would be burnt up; or if she took you farther away from me than she does in summer you would be frozen to death."

"How funny, that we should be frozen in summer or burnt up in winter, and that it depends on how you look at us! I do wish you'd come in our schoolroom a bit oftener than you do."

"What! *I* come into your schoolroom! You did not think when you said that. We have been talking of the effect of a small difference of 3,000,000 miles, and you ask me to come 93,000,000! Remember, then, I never have been in your schoolroom, but I shall 'peep in' as usual and see if you are in your place, and shall send my fairy messengers right down on to your slate to help you to do your sums, and on to your copybook to guide your fingers, and on to your reading-book to light up the page for you, so that the words shall speak for themselves; but please don't forget that I'm always 'on duty' here, and that I never, never leave my post."

"What does Earth go round you at all for? Is it for exercise?"

"She comes to see her father, and holds you up in her arms, by turns, for his continual blessing, without which nothing could possibly live and grow."

"Mr. Sun, have you any sisters and brothers at home?"

"Only about 100,000,000; you've seen them night after night, have you not?"

"But I mean suns, like you."

"So do I."

"But are you a star like those we see on a moonlight night? They are quite little."

"Not if you were close to them. Many of my brothers and sisters are both bigger and brighter than myself. If I were as far away from you, I should look no larger than they."

"I should like to see you at home."

"What do you mean?"

"Among your brothers and sisters. I see you in the morning, but you know you are away at the opposite side of the world at night, when I see the other stars."

"Or rather the opposite side of the world has turned opposite me, eh?"

"How could I see you among the other stars at night? Could I, if I bored a hole right through the earth, and looked down, like teacher showed us with the orange?"

"Yes, but you couldn't do it; it's too hard! How did the teacher say you could see the stars in the daytime, do you remember?"

"Oh, yes! by looking up a tall chimney. I say, that wouldn't need any blackening inside, would it? I don't think they'd let me look. They'd say, 'Now, then, be off with you!' But I know a sweep, and I'll ask him. You wouldn't be a *little* star then, so I should know which you were."

"No, you will never see me as quite a little star, because I am so close to earth at all times; but you might see me among my brothers and sisters. We stars don't go visiting.

We can see one another without. Have you never caught us winking at one another across the sky?"

"But you are 93,000,000 of miles away. You said so just now."

"Oh, that's nothing of a distance in *the Universe* we live in. My nearest brother, Alpha Centauri, lives 224,000 times farther from you than I do, so that you might almost regard me as your next-door neighbour.

Even then it would be a tiring walk to Mr. Alfie's if the 224,000 houses were all in a row. Wouldn't it be a long street!

Alpha Centauri you have never seen; if you did you would not see him as he is at this moment, but as he looked three years ago. I really couldn't make you understand how far he is away."

"Oh, tell me, please, and I'll try."

"Do you remember your very first talk about sunshine? The photographs of me which the sunbeams hurried down with and placed before your eyes on the screen? Those photos. my fairy messengers carried to you in a few minutes. They showed me, as I looked, when they left here. Had they been photographs of my brother Centauri instead of myself, the photographs would have been three years old by the time his sunbeams reached you."

"And should we have had to wait three years for them?"

"Not necessarily, for he sends his messengers constantly. He is always distributing his photographs in those countries where he may be seen. From you he is 20,000,000,000,000 miles distant (twenty millions of millions miles, or twenty billions of miles). In fact, the distance is so immense that you couldn't even count the number of miles if you lived to be three hundred thousand years old, and worked day and night. That is my nearest brother. So now you

are sure when you look up to the stars that you see them, not as they *are*, but as they *were* more than three years ago, and in some cases twenty, thirty, fifty, or even a hundred years ago, or it may be centuries ago."

"Have you any sisters, Mr. Sun?"

"Yes, I have. I will tell you a little secret about one who is very bright and beautiful—a real gem—and perhaps some one will point her out to you. Her name is Vega. You know how long my dear little fairies take when I send them on messages to you?"

"Yes, they get here in eight minutes and a half. They take the shortest 'cut' through the sky, don't they?"

"You are quite right; but suppose you call it a 'path.' You know, by now, that we all have our fairies, just as nimble; without them you could not see the stars at all, though the term 'starbeams' sounds rather odd, I confess. The stars that you see, see you. Well, when you were born I told my sister about the new baby at Mr. Smith's, and she hastened to send off instantly a kind welcome greeting by one of her sunbeams. I see that messenger now; he has never stopped once. Where do you think he is?"

"He must have got lost on the way long ago. Why doesn't he take the message back and say he can't find me?"

"He can find you. He has never once lost sight of you, nor slackened speed, but has come in a direct line from my dear sister towards you. He is now almost half way. When you are a boy of eighteen, if you live so long, he will deliver that message to you."

"Will you please tell me what you are doing just now? I don't hear you give orders to the sunbeams, but I suppose they are busy. They are never idle, are they?"

"Certainly not. They know their duties so well by this

time that to look in my face is all they need. As for myself, I am slowly turning round on my axis—a journey which takes twenty-five and a half days. At the same time I am guiding the planets around me, each in a different path and at a different rate. As I said before, I pay the closest attention to little Mercury, though I can assure you I don't neglect Earth. My fairy sunbeams visit Mother Earth every day, and every moment. I *never* neglect her."

"I think they forgot their message, then, on Friday morning, for teacher had to light the gas in school."

"Still some sunbeams came through, or your way to school would have been dark as a coal-cellar. I know that many of them returned to me a quarter of an hour later, saying that Mother Earth was clad in deep mourning, and that she would admit no visitors. Still I continued to send messages of sympathy all morning just the same. I can assure you I was not remiss in my attentions."

"Then, after all, it's not the sunbeams' fault that we have dull days?"

"No; I would suggest that you talk to Mother Earth about her wardrobe. No one has robes more numerous and varied than she, and that the children who dwell in the folds of her garments should grieve to see her attired so frequently in black is not strange."

"I don't know how to help it, though!"

"No! no! you are but a little boy yet. Earth is a kind and gentle mother, and to my mind never looks so well as when clad in the grey light of dawn, with crimson streaks and golden lines breaking through; or, later in the day, robed in fine white vesicles of mist, which float above the intense blue reflected from particles of air."

"I like sunset best."

"Ah, 'sunset!' that is the time when the earth-children

represent me as 'going to bed,' is it not? I wonder what would become of them if 'I sank to rest,' as they say?"

"Teacher told us people used to wonder at seeing you in the east next morning, when they'd watched you go to bed in the west, and they said to each other that you must have run back across the sky, after dark, when nobody was watching."

"Look for a moment at Earth as she turns before us. Do you see the countries vanishing on our right saying 'good evening,' while at the same moment the countries on our left are greeting us with 'good morning'? So that while the people on the one hand are saying that I'm going to bed, the people at the other side of Earth are just as certain that I'm getting up, at the very same instant; and before they have got the words out of their mouths, the next-door neighbours of each repeat the same strain, and so on, ever. Can you tell me how I can oblige them both at the same moment?"

"I see now what you mean by Earth's holding up all her children in turn for your blessing. Those on our right she is now holding up for a good-night kiss before they retire to rest."

"Just so, and the sunset robes which you admire so much, my sunbeams weave out of the air every day anew for our queen. You recognise the family colours, gold and crimson. They carry the robes when finished, and gently drop them down upon her shoulders, with here and there a touch of the fairy fingers of one and another the whole time."

"I like to hear about the sunbeams. Please tell me something else about them. Do you talk to your fairies, and do they talk to you?"

"Oh, yes. How could they convey my messages with-

out? I don't write them down. You said something about their obeying orders, a while since. I can assure you that is not the way I address them. No, I always speak cheerily and lovingly to them; that's why they flit about so fast. If I were to look dull and miserable they'd break their hearts."

"Do they tell you what they've done and seen on earth?"

"Yes, indeed, and fine fun they have!"

"What do they tell you?"

"Everything. How the children love to play in the parks and feed the swans, and how my fairies follow them home and try to squeeze in with the children, and how some one comes and shuts the door in their faces; and how people draw their curtains quite close and tight across their windows, and then blame my fairies for taking all the colour out of their window drapery."

"Why, surely they must have forgotten that the sunbeams put all the colour into them that ever they showed; and if they took it out again, it just serves the people right for not letting the fairies see what is going on inside. I expect they only did it to look through better.

"I shall have to tell my fairies what a warm champion they have in my little friend."

"Do they always tell you their troubles? Go on, please."

"Some streets they can't get into at all, even to the sick people, who need my fairy nurses to make them well; and in other streets, only when I am standing over them. Then my fairies have to make the best of the opportunity. They might be storming a city. They batter away at the windows trying to get in. Some one comes and pulls down the blinds, quite scared at the sight of a sunbeam. They blaze away on the walls, and make even the bricks quite warm, yet no one lets them in, though they keep rapping

away at the front door, and peeping through the keyhole to see if any one is coming."

"What do the sunbeams do, then?"

"Sometimes they raise up blisters on the front door, to let the occupants know that they have called upon them—a way they have of leaving their cards."

"Do they ever tell you about the flowers and fruit and animals?"

"Very often, indeed. Only to-day they reminded me that they were getting ready a fine field of oats in Scotland. Tommy's next bag of meal for porridge is to come from that field, and four little daisies were tipped with crimson yesterday in Tom's own garden. Now their tiny rays are shut up for the night, but they will open their eyes at day-break, long before Tommy wakens in the morning. Very likely he will see their little eyes watching him about as he sets off for school."

"Oh! do they ever tell you anything about our school? Do you know our teacher? She's always setting traps to catch sunbeams. What do they say about us?"

"They say, about eight minutes to two, 'Now we must be off and perform for those school-children.'"

"Do they like coming to us, do you think?"

"I am sure they do, because I hear them ask the sunbeams that have been as far as the window and back again, how many children are ready waiting. They ask such questions soon after half-past one, and they are terribly afraid lest I shall send them elsewhere."

"I suppose they wouldn't like to be sent off on an errand to Neptune just then? I can fancy I see them hiding."

"Perhaps not; but some one has to go, and Neptune is

not without interest. You see we know the secrets of so many worlds."

"How funny! What else do they say? Of course they like the experiments better than the conversation?"

"Yes, they perform little experiments on their own account occasionally—screen or no screen."

"But what else do they say?"

"They tell me all about it after. They say your teacher makes the holes so small they can't get through."

"Yes, that's why! We don't want a lot of them; they're in one another's way, because each beam prints an image of the source of light."

"You are getting quite learned. By 'an image of the source of light' I suppose you mean a photograph of me?"

"Yes, the sunbeams bring us your photographs, but you know you said yourself, that we could have photographs of other suns. I wasn't thinking of that, though, I was thinking of lamps, candles, and gas as sources of light sometimes."

"There's no puzzling you, Tommy, but I shall try again later on. One day my fairies said they had been dancing on the tight-rope."

"Well, don't they like it?"

"Yes, they are always ready to do anything they can, but they don't like squeezing through those glasses. They say that it's worse than the earth-children trying to crush into the pantomime."

"I like watching them perform, better than going to the pantomime."

"That reminds me, one day they told me they had been jumping through a number of circles cut out in card, just ~e dogs and horses perform in the circus."

"Yes, they have to do that nearly every day before they get through the hole in the blind."

Home Experiment

85. Make an orrery like Fig. 151, with a ball, watch-glass, and tray or dish. (See "Practical Hints.")

CHAPTER XL

TOMMY'S DREAM—PART II

"I WISH I were one of your fairies. I should so like to see one of them; they work so quietly that I can't see them at it, nor even fancy how they do such wonderful things."

"Well, as you have learnt so much at school, I am going to favour you. What would you like them to do? No, you need not tell me, for I can read your face. I've known you from a baby. 'Come, my gentle Ariel, come!'"

[Then I saw a beautiful angel face, almost hidden in the sunbeam; it smiled just exactly as the Sun's face smiled. I think it was a reflection of that smile. Then the sunbeam drew near, and it was so splendid and so warm that I had to move aside. The sun, seeing this, waved him from between us, and I did not see him again. I should have liked a good look at him, but his brilliance dazed my eyes till I could not see. I only heard. I tried again to catch a glimpse of him, but my eyes seemed of no use to me, and when I attempted to raise them I saw nothing but blackest darkness]. I heard the words, "Ariel, to-day must be a bright, warm, sunny day, without a cloud over England, that all the sick people may be tempted out into dens and parks. They've been longing to go out for y a day. What did we last night?"

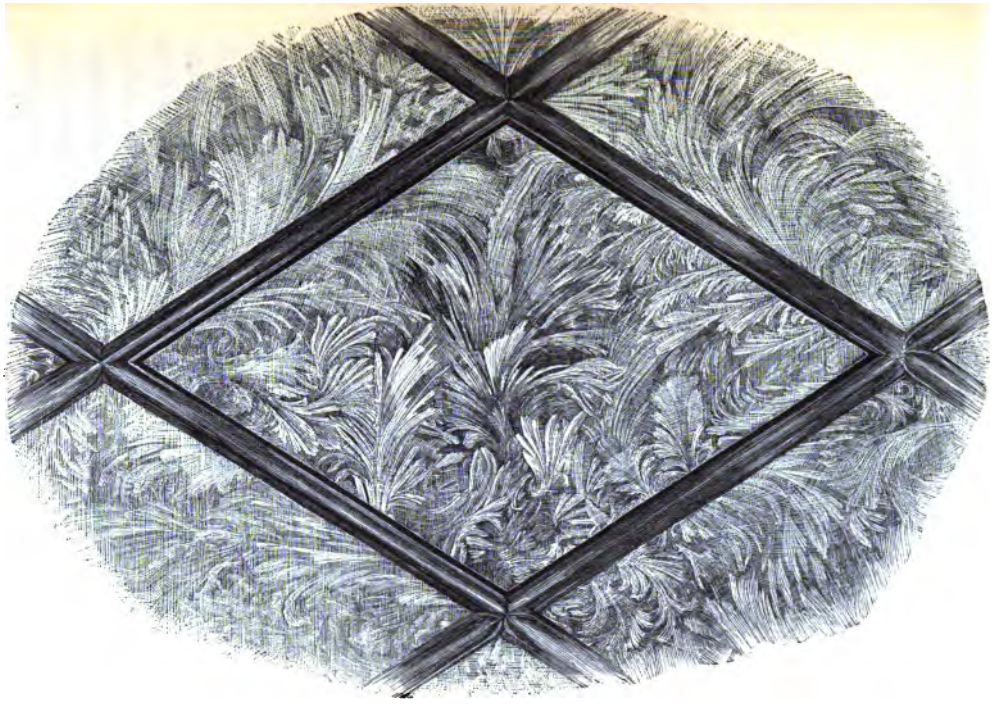

FIG. 153.—THE FAIRIES MAKE PICTURES FOR FREDDY.

"We made pictures of ferns and trees on Freddy Smith's bedroom window, so that they will cheer him when he shall awake this morning."

"Poor Freddy! what sort of a night has he had? Do you think he might venture out this morning? You sunbeams must wrap him round well; make his jacket quite hot."

"We must have a shower to-day, my lord, either of snow or rain."

"Oh! do let it be a gentle, sunshiny shower," I cried, "with a rainbow for Freddy when you waken him up. Please, do. Teacher said early morning was the time for rainbows, and I told Freddy when I came home, and now he looks out for them always."

"Well, we'll see. Are the flowers destroyed, Ariel?"

"No, my lord, the frost was only very slight."

"You may rely on Ariel. Your brother will be quite safe with the sunbeams. The birds will sing their cheeriest songs in the branches; the flowers will put on their loveliest tints; a slight breeze playing on the lake will ripple the images carried by my fairies, into a rough silvery mass. As you walk along the banks, your own images and those of the trees and flowers growing by the side of the water, will be found accurately mirrored there. Now and again, a gentle breeze playing on the water will seem to rub them out, to reappear the next moment. Your shadows will be seen on the bank also. All Nature will be glad and sing together, from the birds down to the tiniest insect. Keep your eyes wide open, listen intently, that you may interpret Nature's song for your little brother."

"How good you are! I'll try to see everything, and very likely we shall bring some objects back with us for the microscope."

"Very well, then, I'll bid you good morning. Now, you can think over what we have said, and go to sleep."

"Oh! please, mayn't I stay a bit longer, if I'm not in the way? Do let me!"

"Well, if you stay, I shall puzzle you."

"Oh, you may try very hard,—I will do my best to answer. I want to ask you one question first, though. Do you like the people who live on earth—Earth's children, as you call them? Which do you like best—old people or young, boys or girls?"

"Is that a specimen of one question, Tommy? We shall have to make you an examiner when you grow up. First, then, I do like Earth's children, and all who are in my care. I behave just the same to all—old and young, rich and poor, boys and girls, though I may have seemed to be favouring Tommy Smith, because you evidently know him. I send my messengers just the same, wherever they let me, both among nice, kind people and those who are neither kind nor nice. I look into English homes, and my sunbeams make glad the heart of the Desert, for God maketh His sun to shine upon the evil and the good, the just and the unjust."

"Please, what are your fairies doing just now?"

"Some of them are busy wakening the little boys and girls in India and China, that they may be in time for school. Others are growing cotton in the fields. Many of them are busy on the other planets; but those you are not so much interested in, and wouldn't understand what they were doing were I to tell you. I shall speak only about those sent to Earth. If you will look at that globe rolling before us, perhaps you can make out Asia; that is the part opposite to us just at present. See, the sunbeams are busy painting the sky crimson and gold. Just a few of

the people are looking out of their windows. Soon I must waken up Tommy Smith. If you watch carefully you will see, by and by, the continent of Europe. Britain will travel this way presently, then Ireland, then America."

"Have you to waken up Ireland and America after us? Won't the children be late for school?"

"No, for I bring the time to them. I am the Clock of the world. I am very, very old. I was here ages before clocks and watches. People still judge their time from their first glimpse of me, though they don't look at me quite so often as they used to (Fig. 154). Your grandfather, no doubt, could tell the time quite naturally by looking where I was, and even you could tell the teacher when twelve o'clock came, had the clock stopped. How would you do it?"

"You are nearly overhead at twelve o'clock; you are in the highest part of the arch you make in the sky, and just in the south."

"Very good. If you watch, it takes nearly half an hour for the Irish Sea to pass before me. So that I call the first little Irish boy up about twenty-five minutes later than you, and yet his clock points at the same time exactly at that moment as yours did when I called you. Do you think he will be in time for school?"

"He will have just the same time to get ready as I shall, if that be so."

"Yes, and an extra hour beside, for, most likely, he won't go to school till ten o'clock. I'm sorry you won't be able to watch him rub his eyes when I glance at him, for you must be up half an hour before then. I shall let you watch till England turns this way, if you are not tired."

"You call the daisies up first, don't you? No, I'm not at all tired or sleepy."

"Just as you sight England, day will be dawning there;

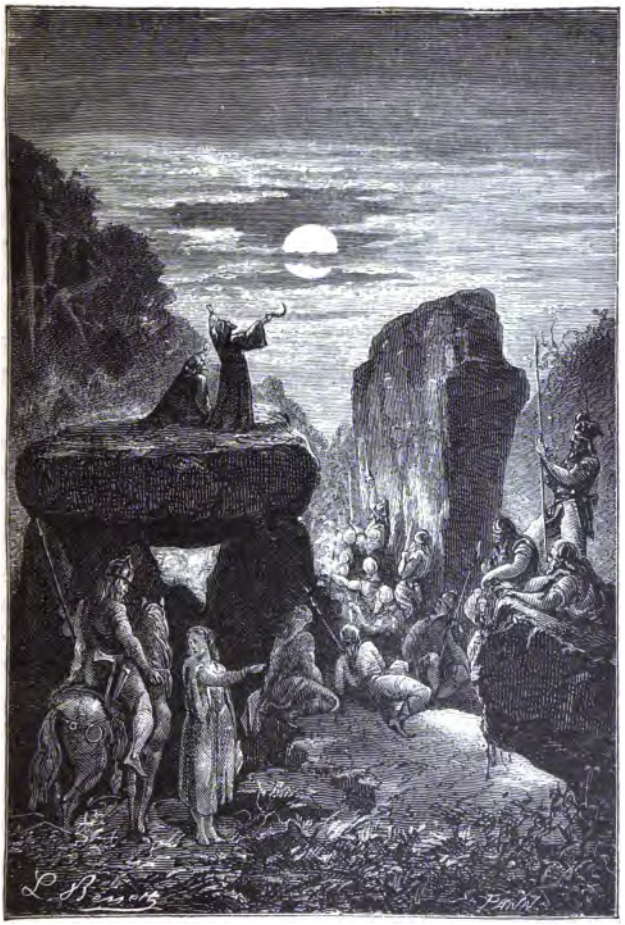

FIG. 154.—DRUIDS PAYING HOMAGE TO KING SOL.

but before that I must make preparations for Tommy Smith, or he will be disappointed."

"Oh yes, I know. Teacher told us you made all sorts of things."

"On the contrary, I make nothing; in fact, *I am made myself.* All that I can do at best, with the help of my fairies, is to separate and re-arrange into new substances, what I find already existing, and to cheer and guide Earth's children in a variety of ways. This keeps us constantly busy and happy."

"But you do just as you please, don't you?"

"Certainly not; I obey orders. I 'do as I please' in the sense that my work pleases me. I would rather do the duty I have, than any other."

"You, the big, big, big, big sun, so immense that we can't even imagine how large you are—*you* obey orders!"

"I—I'm nobody—nothing."

"Yes, you are *Our Sun*—you shouldn't say you're nobody."

"'Big and little' are relative terms; that is to say, they depend upon what you decide to measure with. There are on earth even, beings so tiny that a common fly is quite a large animal in comparison; yet the giant fly would surely not speak of its *immense size* in the presence of the elephant. Although I may seem large to you on earth, in *the Universe* where I live, and you live too, I am no more in comparison than a grain of sand on your sea shore."

"And we live in the Universe, too, close beside you! I am so glad, even though 'in comparison' I suppose I am an 'invisible speck,' as teacher would say, too small to be seen by the most powerful microscope."

"Never mind, Tommy, *I* can see you."

"What do they call that part of the Universe where you ıd I live?"

"It is called 'the Milky Way.' I daresay, you—I was going to tell you something about the Milky Way, but I must not."

"Yes, I know, you are afraid taking the cream off."

"Just so. I must not tell you what you can find out for yourself, and I know you won't rest till you do. There are two ways of getting to know; one is by asking, the other is by reading."

"Then I'll ask you. Please tell me."

"You little rogue, that was not what I meant; besides, I can't show you so well just now. Look out on a star-light night; you will see *part* of that milky band in the sky. It is composed of little specks of star-dust—the like of me,—though, as you rightly said, you won't see your sun at night."

"Please, sir, there's a way of getting to know that you didn't say just now."

"How so, what is it, Tommy?"

"It is a very good way, too, though I've only found it out lately. It's by making experiments."

"But see, isn't that a way of asking questions? Experiment is Nature's language, and if we want to know Nature's secrets, we must learn how to question her. If we don't ask just exactly what we mean to, we can't expect to understand Nature's reply."

"Oh, please, tell me what you are going to get ready for Tommy?"

"I am always helping Tom Smith, but he does not always appreciate it."

"Oh yes, I'm sure he does; but he can't tell you."

"Well, I'll give you an instance. Yesterday morning I woke Tom earlier than usual to finish his lessons, which he had neglected. Did he get up?"

[I said nothing.]

"Perhaps you can tell me something that Tommy does appreciate? I don't think he is an ungrateful boy."

"He thought it was very good of you to fire his cannon, and to make that beautiful spectrum and rainbow in school, and grow the flowers and paint them, and lots of things."

"As soon as Tom rises he will want his breakfast, I suppose. Can you tell me what his breakfast consists of?"

"Oatmeal porridge."

"And that is made of—?"

"Oatmeal and water and a pinch of salt. I've watched mother make it many a time. I know what you're going to ask me, because you told me your fairies were getting ready a field of oats—but they didn't have anything to do with the water or the salt."

"Tell me where they came from? I said I should puzzle you if you stayed longer."

"Oh, I learnt about salt when I was a little, little boy in the infants' school. Salt is got by drying up sea-water."

"Some of it is, certainly. Who draws up the tiny drops of water and leaves the salt behind?"

"Oh, I suppose it is the sunbeams, though I don't understand how they do it. But teacher boiled away the water on the fire, and that wasn't the sunbeams' doing."

"Think, Tommy! have you not in the match, the paper, the wood, and the coal the sunbeams busy at work? And the water—whence came it?"

"Oh, that's rain that was caught in big ponds. I don't see what the fairies had to do with that; but even if they did get ready the meal, and the water, and the salt, they didn't make the porridge. Mother made that, for I watched her."

Fig. 155.—The Park. Tom and Fred look at themselves in the water as in a looking-glass, and they begin to argue, "Do the fishes in the water see *themselves* when they look up, or do they see *us*?" The sensible fishes soon settle the matter by darting away from such noisy lads.

"You confess you don't understand about the water, but you're in such a hurry to go on, that we will come back to that question again. How did your mother make the porridge?"

"She put it on the fire in a pan and stirred it—this way."

"You mean that she put meal, water, and salt into a pan, and put the pan on the fire, and stirred the porridge with a spoon. Now tell me why the spoon does not turn round of itself?"

"It can't. Mother has to do that with her arm—this way."

"And where does your mother get the strength of her arm to stir the porridge?"

"It's quite easy; it doesn't need any strength."

"Not very much, perhaps, but still a little; for if your mother stirred porridge all day she would feel very tired at night. Where did the strength come from?"

"I don't know. Mother says I shan't get strong unless I eat plenty of meat."

"Then it comes from the meat? You mean, I suppose, the flesh of animals, such as cows and sheep? Where do they get their strength from? What do they eat?"

"Grass mostly, I think, but I don't understand how they get strength from food. I only know that people get very ill when they don't eat."

"Let us see, then. Every time a man (or a woman, or boy, or girl) feeds on vegetable food, or upon the animals which have fed upon vegetable food, he takes in the carbon prepared by the plants for their own use."

"I know; and in the carbon are the sunbeams imprisoned still? I see now! But it seems a very roundabout way f eating vegetables, to eat the animals that have fed upon ıem."

"If I had time, I might show you, in the same way, how the fairies not only prepared the porridge, but the spoon that stirred it, the plate and bowl, aye the milk in the bowl—the tablecloth as well; but I think that you can reason it all out for yourself."

"I can about the tablecloth; for they grew the linen, and mother bleached it, by laying it on the grass this week. I told her she was putting it out for the sunbeams to dance on, and she laughed and said she would always be willing to lend them a canvas for their ballroom, because they returned it in better condition than they found it, especially if she damped it first."

"And now I must tell you what my fairies do with the water-drops. Ah, if only you could see them fly down and touch the surface of the ocean! No, they don't make it boil; that is an idea most little boys have. Boiling is only *one* way of separating the tiny, tiny drops of water that hold one another so fast. Even the winds can jerk some of them out of a basin of water as they blow over the top, or out of the wet clothes that have been hung out to dry, or from off the wet streets after a shower of rain. The fairies give a gentle pull, and very, very fine drops of water are raised up, and these are divided again and again, so small as *not to be seen at all.* As they rise, the warm thirsty air seems to drink them up, and sweeps off with them perhaps hundreds of miles away over the sea, till she comes to a shore. Still she drives on, till, perhaps, she is stopped by a mountain or hill; and as she climbs up the cold hillside, numb with the hard work, she gradually loses her grasp of these fine invisible specks of water, which search about for one another, and when they find, hold each other so fast as to become one larger speck. They are still very small, but may now be seen as a white fleecy cloud of water-dust

borne along by the wind. Still the specks search for and find one another, forming larger drops, until the cold, cold air positively can't hold them another minute, and down they come, some straight into the ocean, whence they rose; others soak into the earth and trickle through the ground till they find a way out, as you've seen them spurting from some little hillside in a tiny silver thread. Near by, runs another silver thread travelling in the same direction. These meet by and by, and others join to keep them company, and you hear the merry hum of their conversation as they ripple on to form a stream. Other streams are attracted by the cheerful sound 'to join the brimming river.' The great broad river then rushes headlong into the sea, and finally the little drops find themselves borne straight back to their ocean home, where they are welcomed like lost children."

"Well, it seems to me, Mr. Sun, as if the wind had most to do with carrying those drops of water about on their travels."

"I thought your teacher told you how the sunbeams made the air move on."

"No, if she had I should have remembered."

"Well, I must be very brief. Do you ever sit in front of the fire and watch the smoke and heated gases rise up the chimney?"

"Yes; I know there's a great wind always going up the chimney, because sometimes we put a paper in front of the fire to make the fire burn up, and then I hear the wind roaring like a lion, and once or twice, when the paper has not been properly fastened up, the wind has rushed off up the chimney with it, in an instant."

"Perhaps sometimes you have seated yourself by the fire got nearly roasted in the face while your back has quite cold and shivery."

"Yes, that's when I sit between the door and the fire; there's a great draught comes in through that door even when it's shut."

"So, you see, we can have wind *in* houses as well as outside. That wind from the door rushed through the fire and up the chimney."

"I don't understand."

"Well, instead of the little bits of air, or air-particles, we will imagine boys standing in a row one behind the other—a long procession reaching from outside the door along the hall into the room you speak of. At one end of the room we will place a long ladder, which reaches up to the roof through a door in the ceiling. For safety, only one boy is allowed to go up the ladder at once. As soon as the first boy goes up, the next boy has his foot on the ladder ready to follow, you may be sure, and all the lads push one pace forward and close up the ranks. That is just the way with the air-particles that rush in at your door; they are waiting impatiently for those in front to move on, that they may get a warming and rush up the chimney after them. But why do they go up the chimney, Tom?"

"I don't know, I'm sure. It can't be to look at the stars!"

"No; it is because when air is warmer it becomes lighter and goes up like a balloon. What might you be thinking about, Tom? You look very puzzled."

"I was just thinking, that, outside, the sun-fire was at the top, and the air-particles would have to come down the ladder to us after they had been warmed."

"Does your kitchen get very hot on a 'baking-day?'"

"Yes, mother says she feels stifled; the warm air nearly chokes her."

"You are quite right; warm air does nearly choke one,

either in your kitchen or in a hothouse among the flowers. It is not so refreshing to breathe as cold air, so I tell my fairies not to make the air warm as they pass through on their countless errands, and they never do warm the air if it be kept *quite pure.* I say 'make everything else as warm as you like.' So some of them rush down and strike against the ground, warming it, and come back again; others strike the walls and come back; some strike your jacket and come back; everything they touch is warmed and made comfortable. By and by, the air just over these objects becomes warm, you see. For instance, your jacket and the ground act as little stoves and heat the air next to them, which then rises up and makes room for more air-particles to follow."

"So, then, the air does get warmed after all?"

"Not very much; it is not nearly so warm as you are. Now, Tommy, it's time you went to sleep."

"Are you quite sure that you like all earth-children the same, and that you have no favourites?"

"I said that I *treated* them all alike, did I not?"

"Oh, then, you have some favourites?"

"I didn't say so. I said I rather liked Tommy Smith. If I must confess—I like the babies best."

"Do you? Why?"

"Somehow they're always peeping to see if I'm about, and when they find me, they chatter away in a language no one else understands. You've no idea what a deal they tell me. Then they put out their little arms for me to take them—just as if I could do with them up here!"

"How do you get out of the difficulty?"

"I laugh back at them; then they laugh all the more, I kick and struggle with their nurses in their efforts to through the window. Then they make pretty little

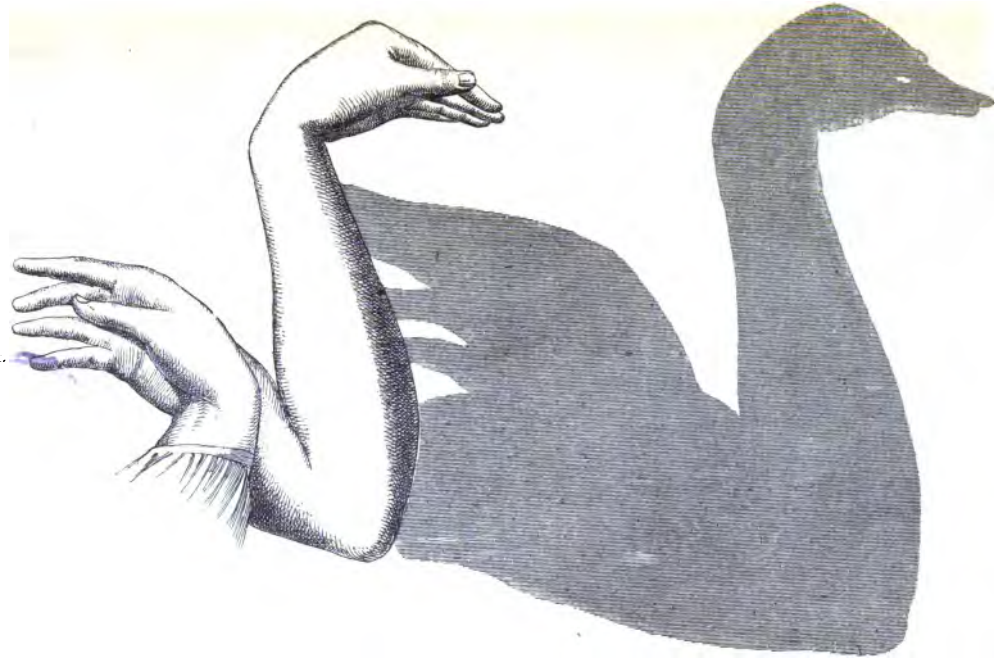

FIG. 156.—*Freddy sees a Shadow on the Lake.*

speeches, of which the last sentence, when translated, runs thus: 'All right, I'm coming out to see you when I've had my bath.' Then the nurse puts baby into a bath, generally too hot or too cold, and scrubs away as if he were a wooden doll. Poor baby's skin is red all over, and he screams with pain. Then I make him pretty soap-bubbles, little and big, to swim about him in the bath, and cling to the tips of his fingers, until he laughs through his tears."

"Is that all. Oh, go on, please."

"After the bath, Nurse proceeds to dress him. His little limbs are stretched and pulled as if he were made of india-rubber—stretched into frocks, and coats, and gloves, and shoes, and stockings. Meanwhile baby keeps up a constant reminder to Nurse of her promise to take him out, only interrupted by speeches addressed to me—speeches so shocking that I should be ashamed to translate them."

"Oh! do, I won't tell any one."

"'I'm coming! I'll *make* them take me out! I shan't stop crying till I see my hat!—I must cry again, now.' At last the front door is opened and he suddenly stops crying almost with a jerk, for he is no humbug, and he bursts out laughing in Nurse's face as she pulls the door to."

"And then—?"

"Nurse laughs too as heartily as he, and calls him a 'naughty boy'; then my sunbeams fly down to him, and play round about him, and make him glad."

[I heard no more. I think I fell asleep after that for a little while, and then I heard the words, "I must go and awake Tommy Smith or the earth-children will be saying, 'What a dark morning; I think the Sun's got up late.'" I saw im look at Tommy Smith's bed, and then I felt the fairies reaming down on my eyes, but no Sun was to be seen, and

I got up and dressed quickly and looked out, and there he was smiling at me.]

Home Experiments

86. Little Freddie is feeding the swans in the park. There is a picture of this on the lake, and also one on the walk. Are these pictures both alike? Would you call them both by the same name? Are they caused in the same way? How do they come there? Try the experiment.

87. Practise cloud formation. (See "Practical Hints.")

88. Mix some salt and water in a tumbler; make the water very salt, but see that all the salt is dissolved. Pour the salt water into a saucer, and place the saucer on the fender in front of the fire. Watch the vapour rise, and notice the salt left behind. Test the saltness of the vapour by condensing some of it thus: lay an inverted saucer over the other, and taste the drops of water trickling down the inside of upper saucer.

89. Make a diagram of the inner planets thus: Dot the centre of a sheet of paper; rule a horizontal line through the dot across the paper; set off the following distances, each measured from the dot, 1, $1\frac{3}{4}$, $2\frac{1}{2}$, 4 inches respectively; with compasses (or drawing-pin and loop of thread) and sharp-pointed pencil draw circles, each from the dot as centre cutting through these points. Over the innermost circle make a little mark to show the position of the planet, and write "Mercury," and opposite to this, on the same circle, write "88 days," representing the year, or time occupied by Mercury in his journey round the sun. In like manner write on the next circle "Venus, 225 days." The next circle is our own; that you can fill in for yourselves. The next is for "Mars"; his year is 687 days.

This diagram does not show the proportionate size of the planets, but only their relative nearness to the sun (which latter, of course, is represented by the first dot you made), also the path each one has to take. You will notice how much longer the journey is, as the planet is farther from the sun. Put the diagram where you can see it every day.

HOME EXPERIMENTS

Camera Obscura

90. In Chapter V. the coloured photograph was received upon the screen upside down. To make the image erect, hold a mirror with its face to the screen, and inclining somewhat downwards. You will now see the images in the glass, right side up, and much brighter.

91. Another way of performing the above experiment so that all can see, is to hold a mirror opposite to the hole where the sunbeam is coming in horizontally. Inclining the mirror, face to the hole, at an angle of 45° (as we did for the sunshine lamps), the erect image may be thrown down on to a table below. This is the plan adopted at the seaside in the cameras you may have seen on the sands.

Spirit-Lamp

92. Make a spirit-lamp out of an ink-bottle. See that the cork is sound. Bore a hole in its centre with a piece of wire heated to redness in the fire; roll a bit of tin (*about* $\frac{1}{2}$ *inch*) round a slate-pencil into the form of a tube, or use a bit of glass tubing or wide glass bead, pushing it into the hole in the cork, which can be widened, if necessary, to receive it. Thread a bodkin or needle with half a dozen threads of white cotton, doubled, and draw it through the cork. Now your spirit-lamp is complete when filled with methylated spirit (see Fig. 73).

The handiest spirit-lamp my pupils have made is from a scent-bottle with a screwed metal top. All that is needed is to widen the bore of the cork. Spirit-lamps must be covered when not in use, or the spirit evaporates.

Newton's Rings

93. Take a small bottle, fill half-full of distilled or clear rain water, and a small piece of soap in shavings. Boil the soap solution over the spirit-lamp, holding the bottle with twisted paper or wooden tongs. After the solution has boiled a while, put the cork in at once and remove the bottle, placing it on wood or cork to cool. When cool shake. A large bubble will form, showing coloured bands, and will last for a long time. Do not remove the cork. The bottle should be of *thin* glass, and be constantly turned round while held in the flame.

94. If you have a little clamp such as is used for screwing sewing-machines to tables, fix two triangles of glass together, and clamp tightly in the centre. You will observe Newton's rings. (Each corner should be held by a binding screw.)

95. A better way of showing Newton's rings is to press one face of a prism on a lens, admit the light through the hole in

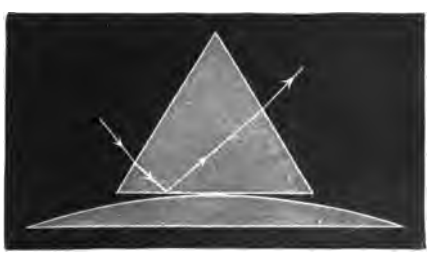

FIG. 157.—NEWTON'S RINGS.

the shutter upon another side, and look through the third side (see Fig. 157).

96. Repeat the experiment, placing pure blue or red glass in front of the hole in the shutter.

97. Examine Newton's rings by *transmitted* light, holding the glasses between the eye and the light. What change takes place? There is a relationship between these rings and those produced by reflection. Can you find it out?

Prisms

98. Try to make a prism of your own, thus: Take three slips of glass of the same length, but of different widths, *e.g.* 3, 4, and 5 inches (or half inches) wide, respectively. Take up the narrower slips and set them on end, resting against the sides of a box or block of wood having a right angle. Having placed the long sides so as to meet at right angles, cement the edges of glass together with Kay's coaguline, binding them with an exceedingly narrow strip of black ribbon or cloth (*if necessary*). Leave the angle of glass resting against the wood until next day, when it will be quite "set," and then fix the third side, which will just fit if you have worked carefully. This prism has three angles, each corresponding with the side opposite to it. You have yet to cement a piece to the bottom so that the hollow prism will hold colourless transparent liquids. Then you can try the effect of each angle in forming a spectrum. Find out which gives the best spectrum, and what liquid is best.

99. (*a*) Fix two long slips of plate glass over each other (but one-tenth of an inch apart at one of the ends) by means of pellets of wax. Now press the plates nearly close together, *making a very sharp angle* at the other end.

(*b*) Look at a candle-flame through the thin prism. Multiple images will be seen, crossed by a series of beautiful bands or fringes. As you press the plates closer at the one end (making the angle still smaller) these bands increase in breadth. This prism with a drop of water or glycerine in the bend, is the one referred to in Fig. 83. It is held in front of *one eye*.

Experiments on Plane Mirrors (Looking-Glasses)

100. Walk up to a mirror. Your image seems to start from the same distance behind the mirror. You walk rapidly towards each other. Where do you meet? Can you shake hands? What hand does the image offer? Can you make the nage give its right hand to yours? Bow and retire. If you out of the door your image disappears through a door opposite.

Hold a book in front of the mirror. Can you read it? Why not? Try if it is upside down. What is the matter with it? Find out if you can. Turn the book till you get it right. Can you? Take another mirror; see if you can get the print right now? Point a toy gun over your shoulder to some object behind you and try to hit the mark. These are only a few out of an endless number of amusing experiments with plane mirrors. Others you can find out for yourselves.

101. It can be shown by a geometrical drawing exactly where the image appears behind a mirror. If you were older, you might make such a sketch for me, and afterwards test its accuracy by experiment. I have thought of a very easy way, by which you may prove that the image occupies a position behind the mirror, corresponding to that of the object in front. Take a piece of tracing paper, and draw upon it any object whatever, or trace a figure from a book. Now rule *a straight line*, in any position, beside it for the mirror. Fold the paper over at this line and trace over the object. Now open it out. Look at the object and its image. Notice that the form of the image is the same exactly as the object, and that its position behind the mirror corresponds identically with that of the object in front. Practise this twenty times at least, making different objects and positions. Distinguish the *object* by drawing it in *colours*.

102. Now you will be in a position to understand "Pepper's Ghost" (Fig. 42) far better than from any words of mine.

(*a*) Draw an object and mirror; fold the paper on the mirror-line and trace the image. Mark this image in some way, as a new object; draw a line beside it to stand for a second mirror, draw its image.

(*b*) Draw an object lying down, feet to the mirror (45°); in what position is its first image? This is our "Turk" experiment.

(*c*) Make the object stand erect before a mirror (45°); its image is horizontal. You now see the use of the second mirror (45°), which causes the image once more to stand erect. There-

fore, to show Pepper's Ghost in action and walking about, a second mirror is necessary. The lower one may be silvered.

103. (*a*) Draw two mirrors at right angles (see Fig. 158). Place an object between and trace its image in each mirror.

(*b*) Trace the position of the mirrors at 45° (Fig. 150), and put an arrow between them. Draw its seven images, first producing the mirrors where they meet.

Fig. 158.—Mirrors at Right Angles.

104. Take two similar mirrors and lay them, *almost* touching each other, on a strip of cloth or ribbon covered with paste or glue. This will make a hinge when dry, by which you can prove the kaleidoscopic effect for yourselves.

105. *Parallel Mirrors.*—The principle in this experiment is the same as that shown in Fig. 36, which might be regarded as consisting of two thin mirrors, one silvered and one unsilvered, joined together. In the following case the mirrors are parallel as before, but the object is placed *between* them. Get a box 12 inches long, 6 inches wide, 6 inches deep—failing this a cigar-box would answer the purpose. Copy a view of an arch, avenue of trees, promenade, country lane, or bridge over a river—say Westminster Bridge by night. Make two drawings or tracings of such pictures, and mount one on each side, reaching from end to end of the box. A few toy soldiers or other figures may be set on the floor of the box.

Place a piece of looking-glass at each end of the box. Remove one of these in order to make a hole (the size of a lentil) in the centre of one end of the box. Replace the mirror and scrape away the silvering in front of the hole so that you

can look into the box. Hold near to the gas so that it will be lighted from the top, then you will see an *endless* avenue of trees or bridges or a long stretch of coast, as the case may be.

Experiments with the Solar Lantern and Simplex Heliostat

106. Fill the alum cell (thin flat bottle without neck) with methylated spirit. Lay a pane of glass over the lower basin, and place the cell on the pane, with a penknife or glass rod; drop gently a *very little* aniline green dye on the alcohol. The dye falls first in a straight line, then branches out in all directions, and looks like a tree growing upon the screen; if a little dye of red or of some other colour be added the two intertwine and produce a very pretty effect. Note, too, that *into however many filaments* one drop may divide, they never *sever their connection* with the parent drop. Thus above, the filaments of green may intertwine inextricably among the red, but all the green filaments (of the same drop) are united, and are *quite distinct* from the red.

107. On to the water surface of the large basin, let fall a single drop of ether, turpentine, or of any "essential" oil, *e.g.* cinnamon, lavender, coriander. Lavender makes particularly pretty figures on the screen.

108. Fill the basin again with pure water, and float on it a piece of camphor the size of a pea (or smaller). It is a most curious sight to see this little body wriggle about. A greasy finger dipped in the water stops it instantly.

109. Float a small boat of tinfoil or thin paper, and put in it at one end a piece of camphor the size of a pea; probably it will move about in a leisurely way. Now drop a mere crumb of camphor on the surface of the water. It will fly up to the boat and pull it about like a little "tug" steamer (Fig. 159).

110. Fill the basin with pure water, dust it with lycopodium, gently place a speck of camphor on the surface. The lycopodium retreats on every side, and finally arranges itself into a number of pairs of wheels, turning in opposite directions.

111. *Spherical Form of Water.*—On the pane of glass over the

condenser, strew lightly some exceedingly fine sand, shaken from a handkerchief; or use lycopodium, or a dusty piece of glass, and on it place a single drop of water. It will gather the dust around it, and on the screen will look like an immense dew-drop.

Lenses

112. We should now be able to find out something more

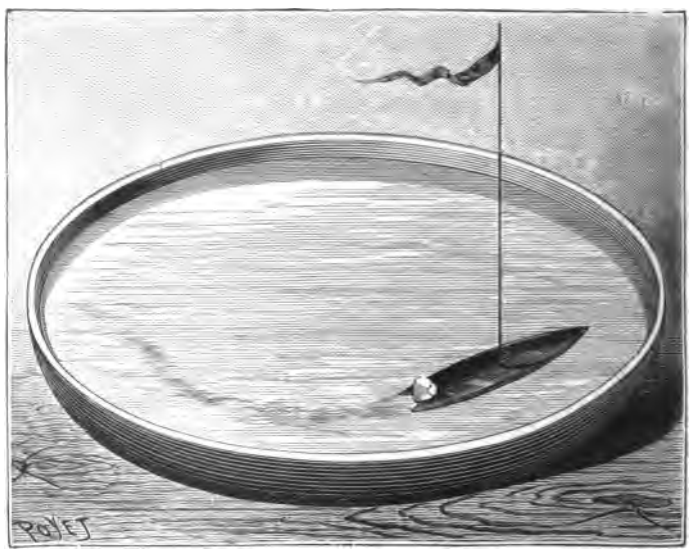

FIG. 159.—TINFOIL BOAT PROPELLED BY CAMPHOR.

about a pocket-lens than the mere fact that it enlarges print. Beginning as before, we lay the lens on our book and notice—(1) the displacement of the print (refraction); (2) raising it gradually and slowly, the letters grow larger, and we see fewer and fewer of them; (3) now they have grown very large and indistinct; (4) and now we can see *nothing*, not even a blur. Why? Because this is the position of the *principal focus*; the rays nerge *parallel*, therefore form no image. If the print be very

small, we will continue our experiment on a bill or the cover of a magazine, which, for simplicity, we will turn upside down. Passing through stages 1, 2, 3, and 4 as above, we continue to raise the lens until (5) we are able without disturbing the book to read the print *right side up* ; (6) and as we continue to raise the lens, the print becomes clearer and smaller, until (7) it becomes too small to be read.

113. *Burning Glass.*—Prepare a piece of charcoal ; make a little hollow in it, and put in a bit of tinfoil. Focus the burning glass, not on the tinfoil, as it is such an excellent reflector, but on the charcoal close up to it. It will melt the tin. Does not this experiment suggest others ?

114. Hold a short focus lens close over the rain-tub when the sun is shining brightly. A cone of light will be formed in the water. Holding a piece of white paper horizontally in the water at various depths, we obtain in each case an image of the sun. Before the rays cross, the disc is bordered with red ; after the crossing of the rays, the border is blue. Notice the bright central ray, also the broken curve.

115. It will be useful to you to know how to find the focus of a lens when sunshine is not available. Place the lens in the middle of a dark room, a candle at one end and a screen at the other. If you work with a companion, one should take the candle, the other the screen, and move pace by pace towards the lens, keeping lens, screen, and candle at the same level. Approach the lens, notice the image, and stand still when the image is exactly the same size as the flame itself. The position of each will then be found to be the same distance from the lens. The distance from either the candle or the screen to the lens will be twice the focal length. Therefore measure the distance, and divide the result by two for the length of focus.

116. If the lens be of *very short focus*, use the Rev. Prebendary Webb's method, thus: Take a sound cork and cut from it three discs ; slide these on to a knitting-needle. To the central cork affix the lens to be tested. Push about half of a fine sewing-

needle, point uppermost, in each of the others. See that the extreme points of the needles and the centre of the lens are in the same straight line. Slide the needle discs along, until the images coincide when looked at through a magnifying glass held in the hand.

117. *Micro-lens.*—Make a powerful micro-lens thus—Reduce some pure white glass to a fine powder. Take up a small portion on a loop of platinum wire, previously moistened with hydrochloric acid. Hold it in the flame of a spirit-lamp or Bunsen burner. It will fuse into a glass bead. Make several of these, and select the best for use. Mount as in experiment 26 (*b*). (Platinum wire inserted in a glass tube as holder is supplied at 2d. or 3d. where the apparatus is obtained.)

118. *Refraction.*—Fill a wide flat glass bottle, having parallel sides, full of water and about two drops of milk. Turn its narrow side to the sunbeam, admitted through the hole in the shutter at such a height as to make the longest possible line in the water. Hold it in the hand so as not to interrupt the beam. Notice how the beam is bent on passing through the water, and again in passing through air (use touch-paper).

119. Repeat the above experiment, placing the bottle on a mirror. The sunbeam is now refracted through air, more so in passing through the water; it is then reflected upwards through water and air.

120. Fill a goblet more than half-full of water, slip half-crown in. Cover with a saucer and turn over. You will now see a magnified half-crown lying on the plate, and another of natural size swimming above it. If you look sideways you will see only the large piece, while if you look down from the top you will see the half-crown its natural size. How is this?

121. Pour a little golden syrup into a glass of water and look through the mixture (not stirred), at different objects. They will be seen higher and inverted. This is the principle of the Mirage.

122. Look at a distant wall or tree, over the boiler of a steam-engine. The wall or tree will appear chopped up into

several portions, and all round these, for a considerable distance above the boiler, you will see inverted images.

123. Some day when the oven is *very* hot I want you to ask mother if you may have an oven shelf lifted out and placed near the window—(1) stand behind it and look *over* it at the scene through the window; (2) place it somewhere near the opposite wall, and, taking a lens in your hand, focus the window-picture on the wall. (A red-hot poker or shovel will answer the purpose, in lieu of anything better.)

Reflection

124. Half fill a basin, say 12 inches across the top, with a mixture of ink and water. Take a strip of strong cardboard, 1 inch wide, and a little longer than the basin. Find the middle point of this, and at one inch distance on each side of it, make a round hole. At two inches distance on each side cut a square hole, a triangular at three, and a star-shaped hole at four inches on each side.

From the centre point hang a small weight by a fine thread, and place the strip of cardboard over the basin, so that the weight hangs in the liquid and keeps the thread tight, without bending the cardboard. On looking at the point where the thread enters the liquid, through the *round* hole, the reflection of the other *round* hole will be seen right behind this point; the *square* hole will bring that of the other *square* hole into the same position, and so with the triangular and star-shaped holes. This experiment shows that the incident and reflected rays are *in the same plane* and make *equal angles* with the vertical thread. Compare Fig. 5, where AD might represent the stretched thread.

125. Perform the experiments mentioned on p. 442.

126. It may be shown by two methods not given in the text that the image produced by reflection is brightest *when the angle is large.* (1) By using a basin of inked water. Hold a candle above the water and notice the brightness of its image. Now gradually lower both candle and eye until the

rays just *graze* the water-surface. Note the increase of brightness. (2) In the experiment shown in Fig. 36 the *second* image is the brightest (in fact, the first is almost too faint to be noticeable), but by placing the candle *against* the glass and looking very much aslant the *first* image gains strength and surpasses in brilliance that from the silvered surface.

Effect of Distance

127. The nearer an object is to us, the *larger* is its image on the retina. Fix a half-crown (or a bright penny) against a wall or a board, with wax, also fix a threepenny piece (or a farthing) to something movable, *e.g.* a block of wood. Stand a little distance (marked) away and look through a pin-hole at both placed side by side. Move the smaller nearer to you until both appear to be the same size. Now stand at a new distance and re-arrange the coins until you again see them equal in size. Don't you think you could arrange this in a long box with a pin-hole at one end?

Spectrum Analysis

128. Produce Newton's spectrum at home, covering half the slit with red, blue, or yellow glass; the two spectra will then be side by side, and you will see what colours are cut out by the glasses.

129. Pass a ribbon, etc., through the spectrum, see page 433.

130. Produce a spectrum, then with a second prism and slit, throw a spectrum over the first. If the spectra coincide, the colours will be strengthened. Now throw the second in some other position, say put the red upon the green—the result is yellow. How different is the behaviour of this red light from that of a red ribbon! Why? Try other combinations and note the effects.

Diffraction

131. To make a halo without lycopodium allow a mirror to get dusty, or shake a little starch or other light powder (through handkerchief) upon the mirror, and incline it to the sun.

132. *Halo.*—You know what puff-ball is? Oil a slip of glass and dust some of these spores on to it. Look at a point of light through it. If your light be too large to show the halo well, rear up a card in front, and make a pin-hole opposite to the brightest part of the flame. Light bends round obstacles set in its path, and in this way the colour-rays become separated.

Fresnel's Mirrors

133. Fixing a small lens over the hole in the shutter, and if possible a drop lens (Fig. 134) in the focus of the same, lay your hinged mirror (Home Experiment 104) like an open book (*almost* flat) on a table just beyond, and receive the images on a screen.

Siphon

134. Make a siphon of straw and a large nut. Pierce the same with a hot wire to admit the straw (Fig. 160).

Reflection Tube

135. A better way of making the reflection tube (Home Experiment 16) is to get a foot of glass tubing about $\frac{3}{4}$ inch bore. Put a pill-box on one end as a cap. Cover the tube with black tissue-paper, and over this paste slate-paper. Pierce a central hole in the cap with a hat-pin, the point of which has been heated.

Carbon

136. Prepare a rod of carbon thus—Take a match and break off its head. Hold a bit of soda in the gas-flame, and when warm, rub the match stick all over with it. Now light the match, and you will have a solid rod of carbon left.

Colour

137. (*a*) Hold up a glass of water. Look on to it; some of the light is *reflected* from its surface, making it shine. Look through it; some light is transmitted through it. Both the transmitted light and the reflected light are colourless.

(*b*) Pour half of the water away. Add a little milk; look down

upon it again; the reflected light is sky blue. Look *through* it; it transmits yellowish light. What is the meaning of this? The tiny particles of milk diffused through the water have power to separate the colour-rays. Add more milk cautiously; the

FIG. 160.

yellow gives place to orange, then red, then the mixture becomes opaque. Is not this similar to our artificial sunset? From it we learn, that the warm tints crimson, orange, yellow, and gold are here transmitted light, and that violet, greyish and steel blue are to reflection, while the tints between are a mixture of both.

138. Lay a piece of blue or red glass upon a slate or slate-paper. Place a candle near and observe its image by reflection. But the image is in its natural colours! Why? Try transmission.

139. Look through a roll of coloured paper at a white wall.

140. Cut out the figure of a man, in red paper, and mount it on a green card. Shake it—notice the effects: (*a*) the figure appears to be in motion; (*b*) the margin of the red figure appears of a lighter shade; (*c*) a deep red wave appears to roll backwards and forwards over the card.

Solar System

141. Make a drawing of the Solar System. Copy Fig. 118, completing the circles. Draw a line from the centre to Neptune; this line will cut all the circles, giving the radii. Make another copy just four times as great as in the figure.

Shadows

142. Take a pill-box, say 1 inch deep, cut a square hole or window ($\frac{1}{8}$ inch) in the lid. Stick a small pin in the lid in such a manner as to appear to look out of the window, its head being on a level with the centre of the same. In the bottom of the box make a pin-hole in the centre. Turning the "window" side to the eye, look through the "window" at the pin-hole, and out beyond at the sky or a bright light. The pin will appear inverted, magnified, and beyond the bottom of the box.

143. Print the letter T on a post-card and cut it out. Hold the post-card close to the eye, and behind it hold a card in which there is a pin-hole. What do you see? A match-box cover does nicely for this; make the T in one of the large sides, and in the opposite one the pin-hole.

Sunbeam Tube

144. Cover a rolling pin with black tissue-paper, and over this roll a sheet of pasted brown paper, closing one end. When this is dry and is still on the roller, lay a halfpenny on the

tube, about half-way, and cut a circular hole. Remove the tube, put the pencil or scissors-point into the hole, and trace a hole of the same size opposite to it; place the tube again on the roller and cut this out. One hole is for the sunbeam to come in at, the other for it to go out at. Having admitted a sunbeam through the side hole look down the tube. *You see nothing.* Why? The light does not *enter the eye*, for it is not coming in your direction. Now make a tiny hole in the tube, through which you can thrust a pencil, etc., into the sunbeam. You see these illuminated objects on looking down the tube. Why?

The Eye

145. We have learned how we see. Rays of light pass into the eye and affect the optic nerve, which communicates their message to the brain. The light of a candle will not affect the hand or foot or any other part of the body except the eye (and the nerve which belongs to it) in the same way. But, strange to say, there are other means of affecting the optic nerve and tempting it to send messages to the brain which are translated into sensations of light. Press on the side of the eyeball. What do you see? Could you describe it?

146. Place a small piece of zinc between the upper part of your gums and lip. Lay sixpence on your tongue. Bring the zinc and silver together. A flash of lightning is seen.

147. We know that in order to see anything *quite distinctly* its image must fall on the yellow spot (*ml*, Fig. 80). Notwithstanding that this is such a very small portion of the whole screen, we contrive, by throwing the images upon it in *very rapid succession*, to see all we want to look at. This we do by *moving the eyes* in the direction of each point of the object, with a rapidity and ease so natural, that we have no idea that we do so. I want you to watch the eyes of some one while they read a page of print.

148. *Iris.*—Stand before a mirror and observe the pupil of the eye grow less as a candle is brought gradually near; watch it grow large again as the light is being taken away.

149. *Blind Spots.*—Fix to a dark wall a disc of paper an inch or two in diameter, and a little lower, at a distance of 2 feet on each side, make two marks. Place yourself exactly opposite to the paper, and hold the end of the finger before your face in such a way that when your right eye is open it shall hide the mark on the left, and when your left is open it shall hide the mark on the right. Look with both eyes at the end of the finger. The paper, which is not at all concealed by it from either of your eyes, will nevertheless *disappear.*

150. *Astigmatism.*—The eye is not equally "in focus" for horizontal and vertical lines at the same moment. Take three strips of paper of the same length and width. Fold one of these to half the width.

(*a*) Lay them so as to make a very wide H, with the narrow strip laid across as the bar. The narrow strip looks longer than the others.

(*b*) Put a pin through the centre of the bar of the H and turn it round to form N. Now the narrow strip appears to be shorter than the others.

151. *Crystalline Lens.*—We said the crystalline lens, with its power of becoming rounder or flatter as required, was equal to a whole series of lenses. Several of you might invest in one or two watch-glasses, and by working together, you can easily prove the truth of the above statement. Take two watch-glasses, a large and a small one, and bring them together under clear water; they will hold together for a little while and form a lens. Fix up the object as in the solar microscope, and use the watch-glass lenses. You will find that the screen distance must be altered according to the roundness (*convexity*) of the lens used.

152. *How one Sense helps another.*—It is believed that we are helped to see things more correctly by our sense of touch. Sometimes, however, sight helps touch to realise objects. Turn the second finger over the first. Shut your eyes and roll a marble about with the fingers so placed. Are there two marbles or one? Look and see for yourself.

153. Prof. Huxley's experiment is funnier still! With your fingers so placed, rub the end of your nose. You seem to have two noses.

154. Hold a strip of white paper vertically about a foot in front of the eyes. Now fix the eyes on some object exactly in front of and beyond the paper. You will see the paper double. Place a candle or other light near to the right eye. Now the left hand (strip) image will be bright green, the other will be red. By placing the light near to the left eye the colours will be reversed.

Vision and the Stereoscope

155. *A Natural Stereoscope.*—This simple stereoscope I recommend all children to make. Get a box of wood or cardboard about 11 to 12 inches long, 6 inches wide, and 3 inches deep. Set it up on a short side, and divide the top down the middle by a vertical line in pencil; you should divide it horizontally also, then the lines will cross in the middle. From this middle point measure on the horizontal line 1¼ inches to the right and put a dot; measure the same distance to the left of the centre likewise. Take a sprig-bit and make an eye-hole at each dot. Widen the holes a little, if required. Put a partition of blackened wood or card down the middle of the box, as shown in Brewster's stereoscope (Fig. 82). Place a stereoscopic slide at the end of the box, and look through the holes. Perhaps the slide will require moving a little nearer—you will soon find the exact position. Then make a slight notch in each of the long sides, and put a black thread across at that place. This will hold your slide erect. You can put other notches if you are careful to measure equal distances on each side of your instrument. If you would like some more slides similar to Fig. 83, the Stereoscopic Club will kindly send you some if you apply to the secretary, Mr. W. I. Chadwick, St. Mary's Street, Manchester.

156. *Distance.*—Shut one eye. Now thread a needle, or pour out a glass of water. As I write this, I involuntarily close

one eye, and I find that I am poking my pen about *outside* the inkstand, instead of dipping into the ink. This shows that we need *two eyes* to judge of *distance.*

157. Hold up a finger; look at the wall beyond, first with one eye, then with the other. If I see a single image of the

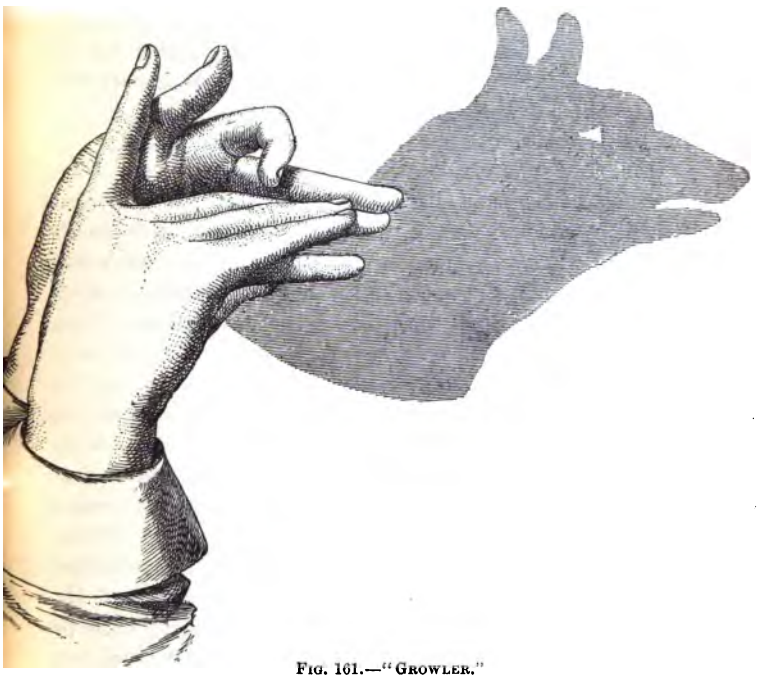

FIG. 161.—"GROWLER."

wall, then I must see two images of the finger; and *so it is*, for the finger appears *in two different places.*

158. No doubt it seems strange that the right eye should see a little farther to the left, and the left eye a little farther to the right. But now stand straight in front of the window and look out. Ah, I hear music! It is a military band! The

sound tells me that it is *on my right*, up this street, coming this way. Where shall we catch the first glimpse of it? Shall we move to the right or to the left?

If you don't hear the music now, perhaps you know of a tree or a lamp-post, just by your house, but out of sight as you stand; move until you catch sight of it. Perhaps your window is in three parts (not a bay window), and is covered by three blinds—a wide one in the centre and two little narrow ones at the sides which you have often admired. Let us draw the middle blind down. Then the two little windows are in a similar position to our two eyes. Think this out quietly.

159. Test the matter in yet another way. Place the thumbs together, and the first fingers together, making a triangular window. Close the left eye; look through the triangular window at some conspicuous small object, say a door-handle, occupying the angle at the left-hand side. Open the left eye, close the right; now the handle is not seen at all, and you are looking at your *hand*.

160. *Substitute for the Stereoscope.*—Hold a black card of 10 or 11 inches long against the forehead, between the eyes, just above the nose; this prevents the right eye from seeing the left-eye picture, etc. (Otherwise each eye sees both pictures: of the four thus seen, the two near ones combine and *stand out in relief*, as in the next experiment.)

161. *Similar Objects.*—Take two halfpence; place them close in front of the eyes (wide open). Look out of one of the top panes of the window. With the eyes so directed, gradually draw the coins forward in the same straight line; you will then see a halfpenny occupying a position mid-way between the real ones, and somewhat farther back, which, though a mere image, will appear much more round and solid than the others.

162. *Dissimilar Objects.*—Nor is it only when the objects are exactly alike, that they may be caused to combine, though this is not strictly *stereoscopic* vision, for the term means "seeing solids" (or seeing the objects about us *stand out in relief*), and

this we owe to our *two eyes acting together on one object.* Roll a piece of paper into the form of a tube about 12 inches long; hold it by the right hand close up to the right eye, and look into it. Now place the palm of the left hand opposite to the left eye, and resting against the tube at about an inch from the end. *Keep both eyes wide open.* We see the inside of the tube with the right eye, and the palm of the hand with the left; but we *appear to see* a combination, resulting in a *hole in the left hand.*

163. (*a*) Place a stool or books on the table, until the top is on a level with your eye. Set two small objects near the edge, almost close together. Look at one with each eye (moving the articles, if required) until they combine. Perhaps you may find the card mentioned in 160 helpful.

(*b*) Do not move the objects this time, but walk backwards until the correct position is found.

164. When the objects are small and near together they are not difficult to combine. Take an ordinary handbill, and select two letters side by side about half an inch high; hold them near to the end of the nose at first, and gradually draw them further away.

165. Choose similar and near figures on calico print, and treat them in the same way. I selected some ovals on a turkey-red quilt, and they stood up like lemons; others looked like a dish of plums.

166. If we can look *through* the objects we need not look at them in the above way; we can look *beyond* them. Take a cane chair, or one having a perforated wooden seat; lay its back on the table, so that the seat is vertical. Select two holes near together (one opposite to each eye), or retire until such a position is gained. Look steadily through the holes at a candle-flame, until the candle appears to be seen through only *one larger* hole.

Various.—Refer each to its own cause.

167. Pass a bright red ribbon through the spectrum; held in the orange rays one edge appears red, the other bordering on the yellow rays is black. Why?

168. Get a bit of broken plate having black or dark blue figures upon it, such as the "willow pattern." Put it into the hottest part of the fire at night. When you have taken the red-

FIG. 162.—WILLOW-PATTERN PLATE.

1. Before heating (dark blue figures on a white ground). | 2. After heating (the *pattern* shines forth with a brilliant light).

hot piece out of the fire, turn out the gas and examine it. The dark blue parts *absorbed the most rays*, and now they are giving them back, for that bright light shines from them. We have what we call *a negative*, that is, the white parts in the original are here dark, the dark ones light.

169. *Colour Disc.*—Make a colour disc to twirl on a double string. You will require sheets of paper of good deep colours, out of which to cut circles, also cardboard of the same size. Make the disc as large as you can, say the largest circle you can cut out of half a sheet. If you desire a little disc (4 or 5 inches in diameter) you may buy packets of colour circles (kindergarten) from the scholastic stationers'. Having cut out your seven discs of rainbow colours and your two discs of cardboard, take one of the latter and fix to its *exact centre* a small linen button having two eyelet holes. With thin glue, or very strong gum, brush all over the second cardboard disc and attach it to the first, with the button between the two. When quite dry paste slate-paper over both sides. Pierce through the eyelet holes. Now take your colour discs and fold each one *exactly* in two; repeat, repeat again, and yet again. Open it out—there are

sixteen divisions, if you have worked correctly. With a sharp knife slit the N., S., E., and W. lines nearly to the centre. Take each disc in spectral order, and paste down its centre to the cardboard (as Christmas roses are made). You must attach nearly *as much as will cover the button*, but do not arrange the circles on the disc so that all the slits run N., S., E., W.; vary them. Pierce the eyelet-holes again. Now thread a string through two holes of a large (metal) button; now put the ends through the centre of the disc and tie. Your disc is now complete. I need not tell you how to twirl it; every child knows that. You will find it quite easy to fold your colour discs so as to expose a varying amount of each colour, and thus produce new combinations. On the other side of the disc I should like you to invent something of your own.

170. Write your name with a quill or a broad-pointed pen; dry the writing with blotting-paper. Look at the blotting-paper. You could not write like that if you tried! Yet it is your writing. Hold it before the looking-glass. Can you read it now?

171. Set your very thin prism with its open side in water coloured with a little red ink. The water rises between the plates. Why?

172. Look at the sun or the electric light, through a delicate feather pressed *quite close to the eye.*

173. Rub together two milk-stones (quartz-pebbles) in the dark.

174. Hold in the hand a white basin or bowl, the larger the better, with the hollow side turned towards a candle a few feet distant. Tilt the bowl a little. You will observe a shadow. Besides this you will see a *luminous surface*, called a *caustic*, caused by the *crossing of the rays* of the candle on their return journey after reflection from the concave surface, since these reflected rays do not all meet in *one* point or *focus*. By tilting a bowl of a foot or more in diameter, at different angles, a variety of figures may be produced, some resembling fans, others

the wings and tails of fishes similar to those of herring and mackerel.

175. Almost fill a glass with milk. Place a lighted candle near. Notice the *caustic curve* reflected on the surface of the milk. You may have observed the same curve, in the gas-light, upon a cup of tea with plenty of milk in.

176. When you see the sun reflected brightly in a street lamp, stand still and *almost* close one eye. If you move on far, you will soon lose your lovely diffraction spectra. Why? Because the reflected light no longer enters the eye. You are going out of its direction.

177. The scattering of light on a rough surface is well shown by what may be called the *magic picture.* Prepare a number of pictures by writing or drawing on glossy cards with a mixture of chalk and weak gum. The cards will seem to be blank as before, and may be put away for future use. If some powder-blue or coloured crayon be rubbed all over the card, those parts altered by the writing, alone will be affected, and the lines of the design will soon appear.

APPENDIX

(The figures in black type refer to pages in the volume)

THE MISSION OF THE MAGIC LANTERN

A Commentary on the Preceding Chapters

[SPACE forbids any lengthened championship of the Lantern as an Educator. The subject has been dealt with by an abler pen than mine,[1] and the results of that advocacy are too widely known to require reproduction here. The immediate formation of a National Lanternists' Society of over 200 members, pledged among other articles, to devote a portion of their time in lighting up the dark places of this land, *e.g.* slums and workhouses, has encouraged me to make such annotations as, lying outside the scope of my "Little Folks' Lectures," may serve to adapt them to the Optical Lantern. I may here remark that no better practice could be afforded the amateur Lanternist, for the mastery of his instrument, than is gained in illustrating a course of experimental lectures on Light.

Roughly speaking, about half of the book can be reproduced in the evening *by Helpers who do not possess a lantern*, and still more, by those who care to sacrifice Saturday afternoon. Wherever it can be done, the *dual* system will be found to be preferable—the lecturer devoting his attention exclusively to the spoken

[1] "The Mission of the Magic Lantern." W. T. Stead. (1d.) Reprinted from the *Review of Reviews*, Mowbray House, London, W.C.

part, the demonstrator taking charge of the lantern, making the experiments, and showing the slides. A rehearsal will cause the parts to run more smoothly together. Beginners should first master the notes on *the Lens*. Future success hangs upon this.

In a few of the *adaptations* I have made free use of *Light: a Course of Experimental Optics* (Macmillan), in which Mr. Lewis Wright has simplified several of the more elaborate arrangements of Professor Tyndall. In the *theoretical* portions, I am chiefly indebted to our great masters in their several departments.]

1. The solar rays at a distance of 93,000,000 miles from their source may be regarded as *parallel*. Our first concern, then, will be to produce a similar parallel beam with the lantern.

The Science and Art Department make this condition a *sine quâ non* in allowing the grant for apparatus: in reference to the lantern, it is stated that it must be "capable of producing a parallel beam," and yet I know of no maker for the Department who complies with this regulation, though there is no reason why the proper system of lenses should not be employed. I have made arrangements with Mr. Chadwick to supply (for about 15s.) a combination of lenses which shall fit any lantern and produce a parallel beam.

The expedients employed to produce a more or less parallel beam *with the ordinary system of lenses*, are—

(*a*) A parallel beam is produced by a *point of light* placed in the focus of a parabolic reflector.

We may dismiss this as an almost *ideal* case. The electric arc is the only source which approximates to a point. Some *small* electric lamps have been introduced into the market; but, so far as I can learn, no one seems disposed to give the moderate priced ones a very high character. Otherwise, this is just what would suit us best—the Sunshine Lantern could then be employed.

(*b*) All sources of light, being of sensible dimensions, produce

more or less divergent beams. Therefore a *section*, so to speak, is employed.

In *circular* pencils, the most parallel portion (*i.e.* the central) only is employed; but more usually a *vertical* section is made. First remove the objective (small lens), and push the lime forward into the (principal) focus of the condenser (large lens). Cover the lantern nozzle with a cap of tinfoil pressed on. In the *centre* of the tinfoil, and also in a black card or metallic plate, make either a slit or circular aperture as required, the aperture in the card being slightly larger than that in the cap. Place the card in the slide-stage.

(*c*) In such experiments as the "knife-turning," the pulsometer, etc., the circular aperture is used, and a loose focussing lens is employed.

CHAPTER I

1-4. 2. *Images of the Source of Light.*—Remove all lenses. Cover the lantern nozzle with a cap of tinfoil. With a darning-needle prick holes, one at a time, in the tinfoil. Bring the lantern nearer to the screen than usual. Vary the source of light, *e.g.* limelight, lamp, candle, etc.

5-6. 3. (*a*) Every point of the source of light sends out rays of light *in all directions*; some of these rays go through the hole. The ray carries with it the *colour and form* of the point whence it issues, and prints the same on the screen. The sum total of these rays form on the screen an inverted image—inverted because the rays *cross* at the aperture (see Chapter II.) The boundary of this image is formed by drawing straight lines from every point of the outline to the screen (as in Chapter II.)

(*b*) *Form of Solar Image independent of Shape of Hole, if small enough.*—This is due to the angular magnitude of the sun. Were the sun a *point*, the spot of light would correspond in shape with that of the aperture. Describe on paper a figure similar and equal to that of the hole, say a square or triangle. Let us suppose the aperture triangular. From every point of its

periphery as a centre describe equal circles. While these circles are small, you will have at first a triangular figure with rounded angles; but if the magnitude of the circles be increased more and more, till the radius be much greater than any of the dimensions of the figure, it will be noticed that it becomes rounder and rounder, and at length becomes practically a circle. When a paper is held very near the triangular hole, you have a mixed image of the triangle and circle, but if it be removed to a considerable distance, as each circular image becomes then very large in proportion to the diameter of the hole, the image is sensibly round. This principle can be easily verified by holding a paper at different distances from a keyhole. If the disc of the sun were square, and the hole round, the image at a certain distance would be a square, or the same figure as the disc.

CHAPTER II

9. 4. In Fig. 4 the hole in the blind is made with a fine needle, and light is reflected into the room from outside by the arrangement shown in Fig. 6. With the lantern use the tin-foil cap, making a fine hole in the *centre*.

10. 4*a*. Refer to the use of the Search Light.

12. 5. In Fig. 6 the artist has deviated somewhat from my sketch, in which the boy was holding the mirror under his chin. The latter will be found the *best* position for the mirror, the least fatiguing, and most controllable. Practically the height of the boy or his distance from the sight-vane will determine the question.

6. The light from the lantern may be brought down on any of the various mirrors by raising up the back of the lantern.

13. 7. Use a swing looking-glass and parallel beam for the telegraph. The Morse Alphabet is given in Practical Hints.

8. A sunbeam tube is described in Home Experiment 144 which illustrates this point admirably.

14. 9. *Snowflakes* (Fig. 7).—It seems too obvious to tell any one that "these are *faithful* images"; but on showing the proof

to various people, the comment has been "*Snowflakes*?—highly idealised, *of course.*" Nature requires no such aid from art. It is because people see snowflakes *en mass* that the beauty of form is overlooked. Isolation, even *without magnification*, is sufficient to reveal this beauty. I was particularly impressed with the fact one day when a few flakes fell upon a Shetland shawl. Each snowflake stood upon its scarlet fibre as though it rested on the point of a very fine needle, and the form of each ray was perfectly distinct.

CHAPTER III

17-23. 10. *A Shadow Pantomime.*—This being an exceedingly popular and simple entertainment with children, the chapter has been so profusely illustrated as to leave little need for hints.

However, as it is one in which the lantern is best dispensed with, there is no reason why it should not minister to children's delight more frequently than is now the case. Having recently witnessed the *unique* performance of a *specialist* in Shadowgraphy, I was curious to know what arrangement he adopted. He told me he used a blow-through spirit jet, with the lime cylinder sharpened to a point like a pencil. For the latter part of his entertainment he placed behind the screen a kind of stage-front, probably cut out in mill-board, and raised up on a table or board. A street scene can be managed very well by this means. All that is necessary is to run a number of toy omnibuses, carts, and waggons across the table, while various street-cries are produced behind the scenes. The same objects in different order pass and repass before the spectators.

11. (*a*) Shadows are a proof that light moves in straight lines. If the source of light be a *point* we have a *sharp* shadow, but *if larger* we have also, surrounding the perfect shadow (umbra), an imperfect shadow (penumbra). Therefore in projecting shadows we use a *point* of light, or the nearest approach; failing that, the *edge* of a flame. The angular magnitude of the sun destroys the sharpness of solar shadows. To see the shadow

of a hair upon a screen, we should have to admit the light through a pin-hole.

(*b*) Place an orange between a point of light and the screen; its image is a *divergent cone, sharply defined.*

(*c*) With a spherical source of light the shadow of a sphere of the *same size* is a *cylinder*; of a smaller size, a *convergent cone.*

(*d*) Because the sun is larger than either earth or moon, therefore the shadow cast by either is a convergent cone surrounded by a penumbra. An eye in the *umbra* sees a *total eclipse* of the sun; in the penumbra *a horned sun*; near to, but just beyond the apex of the shadow-cone, *an annular eclipse.*

12. The hand-shadows given here are selected from a large number, as being extremely easy, and requiring no unnatural twisting of the hands. Two curious shadow-effects are given in the Home Experiments 142, 143.

13. *Smoked Glass.*—Warm a piece of glass and rub it over with a paraffine-wax candle; heat the glass more and drain off the excess of wax. Now light a piece of camphor and hold the glass over the dense smoke.

Chapter IV

24-30. 14. This is merely a variant of the first experiment, *brightly illuminated objects* being substituted for the sun or flame. The subject is fully treated in Chapter XXXVII.

27. 14*a*. The Darkened Chamber (Fig. 12) consists essentially of two boxes, of which the smaller (M) carries the ground-glass screen and slides into the larger (N) for focussing purposes. The lens tubes A B are likewise adjusted by turning the screw V.

Chapter V

31-37. 15. *Roughness.*—The effect of roughening the reflecting surface may be shown thus: Fill a basin quite full with water, to which a little black ink is added. Throw down the lantern beam on this and reflect its image on the wall or ceiling. Now *blow* upon the water and note the effect. The irregularly

reflected light spreads out into *a luminous column.* See also Home Experiment 157.

16. Standing on a bridge on a calm night we observe images of the lamps on the bank of the river reflected therein. From the same bridge on a stormy night we observe that these images are disturbed. The eye, catching a ray here and another there, sees merely a pillar of light.

38. 17. *Knife-turning Experiment.*—Refer to Note 1 (*c*). This experiment can be done at any time on a table laid with a white cloth, by simply holding the knife perpendicularly and turning in the fingers, the diffused light being quite sufficient to show the effect to those around.

Chapter VI

40-49. 18. The bottle described in the text is suitable for a small class or private experiment, but for platform use a tank

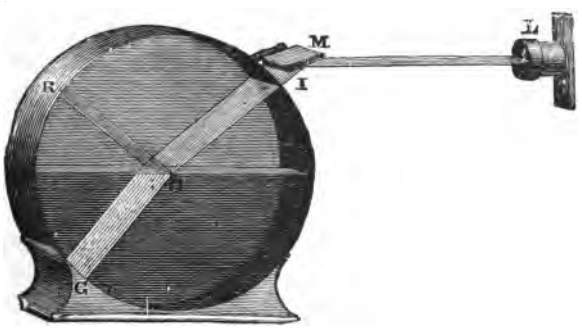

Fig. 163.--A parallel horizontal beam (I) from the lantern (L) is deflected by the mirror (M), and impinges upon the water at O, where a portion is *reflected* to R and a portion *transmitted* (being refracted) to G.

should be substituted. Fig. 163 shows the form ordinarily employed, but this is somewhat expensive. Procure a biscuit-tin with a glass front, which must be made water-tight with marine glue. Some makers put up half-tins of biscuits, which tins answer this purpose admirably. Cut a large circle out of the front side,

and cement a pane of glass against the remaining tin. If the box has already a glass front, to add a circular mask of black paper is all that is necessary. Instead of inking lines upon the glass, stretch a fine cord in each direction, and fix the ends with shellac.

19. So far we have been concerned with light reflected from surfaces, but what becomes of the rest of the light? (see Chapter X). At a *perpendicular incidence* glass *reflects* 1·8 %, water 2·5 %, mercury 66·6 % of the total rays. When light passes from a rarer to a denser medium the refracted ray is *usually* bent *closer to* the normal. Part of the beam is reflected, part *absorbed*, another portion is transmitted. It is with the *transmitted* portion we are now to deal, *e.g.* 98·2 % of rays incident normally upon water.

20. The law of refraction is thus stated: "*The sine of the angle of incidence divided by the sine of the angle of refraction is a constant quantity.*" We obtained the sines of these angles. This constant quantity is called the *Index of Refraction*, and from the text will be understood, in the case of rays passing from air into water, to be $\frac{4}{3}$; since the sine of the angle of incidence (*in air*) was found to be *four* units, and the sine of the angle of refraction (*in water*) was found to be *three* units. This index is more frequently expressed in decimals, thus: (air into) water, 1·336; vinegar, 1·344; brandy, 1·360; rectified spirit of wine, 1·372; oil of almonds or olive oil, 1·470; oil of turpentine, 1·605; oil of aniseed, 1·538; oil of bitter almonds, 1·471; bi-sulphide of carbon, 1·678; phosphorus, 2·24.

42. 21. Fig. 19. *Apparent Raising of the Bottom of a Vessel or Lake.*—Fix your attention on a particular spot (*o*) at the bottom. Many rays issue from this point: one only, viz. the normal, reaches the eye direct; the others, in passing out of the denser water into air, become more divergent, *i.e.* they *fall* more. Disregarding the change of medium, produce these rays backwards; they intersect at a point (*o'*) corresponding with that here the image of the bottom is seen.

22. By looking *more obliquely, e.g.* from a distance, into the lake, the water appears *still shallower*; on approaching the lake the image of the bottom lowers, until, when the eye is brought exactly over the spot, the image is formed at a place three-fourths of the *actual* depth.

23. The lower part of a straight stick thrust into water appears to rise in the same way. Thus the stick appears to be hinged or bent upwards from the point where it touches the water. The same reasoning applies. Note that the stick, unlike the beam of light, is bent *away* from the normal on entering the water. The appearance of the stick in water may be represented by a partially opened pocket-knife.

24. When the beam is admitted into the tank, just so as to graze the surface of the water (incidence $89\frac{1}{2}°$), the angle which it makes on the other side of the normal as it tracks its way through the water is *about* $48\frac{1}{2}°$. This point should be noted on the circumference. It corresponds on the clock face to 22 minutes to the hour (*accurately* 38 minutes 9 seconds past the hour).

Conversely, if a beam of light be sent *up* through the water from this point it will *just* emerge, almost grazing the water surface.

Any beam incident at a greater angle will not emerge, but will be totally reflected from the under-surface of the water. Therefore this angle (48° 27′) is called the *critical* or limiting *angle for water.*

25. The critical angle for flint glass is 38° 41′, while for diamond it is 23° 42′. Realise what this means in the case of the diamond. That light only which is incident so as to be refracted to some point between the half-hour and four minutes beyond (still using the clock illustration) is transmitted; *all other light falling upon the diamond is reflected internally—not one ray is absorbed or transmitted.*

26. Not only do liquids and solids *reflect and refract the rays of light,* but gases in a feebler degree produce like effects. Thus,

similar to the apparent raising of the bottom of the lake, we have an apparent raising of the sun and other heavenly bodies, in our air-ocean, so that we see the Sun before he actually rises, and after he actually sets.

27. The air is constantly in a state of *unsteadiness*, owing to the different temperature and therefore density, of contiguous portions. The quivering and disjointed appearance of objects, viewed through air rising from a heated surface, may be demonstrated by throwing a brilliant *divergent* beam upon objects placed between the lantern and the screen, and holding under the beam a red-hot shovel. On a smaller scale the heated air above a candle, gas, or lamp shows how this irregular refraction incessantly shifts the rays of light.

27*a*. *That the Deformation of the solar Disc* when on the horizon, as at sunset, is due to atmospheric refraction may be shown with the lantern thus: Use the parallel beam through a hole half an inch in diameter, and employ a loose focussing lens to sharpen the image of the aperture on the screen. A little nearer to the screen, now interpose a red-hot shovel parallel with the beam, or immediately below it. The current of heated air will distort the image, drawing it out, and may even form another disc near the first.

28. We found that when the lake was distant, or in other words, when *the incidence was more oblique*, the image of the bottom was nearer the surface. Apply this principle to *aerial* refraction. The sun heats an expanse of sand, the layer of air immediately above becomes lighter than the air around. Rays from *distant* objects may strike the upper surface of this layer so obliquely as to be beyond the critical angle, thus totally reflecting the images, as does a surface of water. The traveller in the heated aerial ocean (of the desert) is in an analogous position to the bather in the water ocean, and, like him, on glancing upwards es the inversion of scenery. "By such delusive appearances thirsty soldiers of the French army in Egypt were greatly talised."

47. 29. *The Law of Reflection* relegated to the Home Experiments is thus publicly demonstrated. A beam is sent through a horizontal slit ($1 \times \frac{1}{8}$ inch) in blackened card. At three or four feet in front of the nozzle is placed a swing looking-glass. A cork is attached to the edge of the mirror against the pivot, and into this cork a knitting-needle is inserted perpendicular to the mirror. It will be observed that whatever be the inclination of the mirror, this index or normal always bisects the angle formed by the incident and reflected beams. Note that the lantern beam must always be directed on the *centre* of the mirror.

30. If numerical proof be desired, substitute for the knitting-needle a *thin* pointed lath turning on the pivot, but cemented to the mirror. Draw on the blackboard a large arc, using the index as radius. Divide this arc into as many equal spaces as desired, and number the same, calling the lowest 0. Draw up the board *vertically* against the mirror so that the incident and reflected beams as well as the index may point to the figures thereon.

CHAPTER VII

50-65. 31. The rainbow, beyond what is dealt with in the text, does not come within the scope of these notes. Dr. Tyndall in his *New Fragments*, just published, has a most interesting article upon the rainbow. I regret that the same appeared some months too late to be of service to me. Still I do not see how any more of the subject could have been simplified, or how the experiments which Tyndall made can be performed on the lecture-table. The lanternist should by all means see the paper.

64. 31*a*. The triple rainbow (Fig. 29) was observed on the Ketima Mountains, 17th July 1736, by the Academicians despatched to the Polar regions to measure an arc of the Meridian.

Chapter VIII

66-73. 32. ***Refraction of Glass.***—A slide with a hymn or some printed matter upon it, or even a smoked glass with horizontal and circular lines made upon it, is projected on the screen. A piece of the thickest plate-glass available is interposed, at first parallel with the screen, so as to cover a portion only of the lines. Gradually holding the glass more and more obliquely, the lines are distinctly broken.

The above experiment may be varied by interposing a cell (1) half full of water, (2) by *gently* pouring on the water a layer of alcohol, (3) adding above the alcohol a layer of ether.

33. *Pure Spectrum.*—When light passes through a wedge-shaped piece of *any transparent substance* in a direction *perpendicular to the edge* of the wedge it is *permanently* refracted. The *larger the angle* of the wedge the more is the light refracted. But the amount of refraction depends not merely on the *refractory angle* of the wedge and the refractive index of the substance, but also upon the direction in which the rays fall upon it.

33*a*. The deviation is least or *minimum* when the portion of the ray within the prism makes equal angles with the two sides of the prism. How this position of *minimum deviation* is found is shown in the text. This is the position of *best definition*.

33*b*. Newton made a round hole in the shutter. Imagine the hole to be composed of a number of narrow slits parallel with the edge of the prism. Each slit produces a spectral image of its own. These images, like the pin-hole images of the flame, encroach and overlap, producing blurring. There is overlapping *on the screen*, even when a narrow slit is used: to remedy this a lens is interposed (see Practical Hints).

34. With the lantern, the slit should not exceed $\frac{1}{8}$ inch in width. A prism bottle filled with carbon bi-sulphide will give much richer colours than a prism of glass or water. Sir David Brewster found oil of cassia to be the most dispersive substance. If a long spectrum be desired, send the light through a condenser

of one or two feet focus; near the focus interpose a card having small circular aperture, to cut off the marginal rays. By inclining the screen to the spectrum it may be still further lengthened out.

35. *Further Experiments with the Spectrum.*—I. (*a*) Pass a black ribbon successively through the colours of the spectrum. It quenches all of them. (*b*) Pass a red ribbon successively through the colours of the spectrum. In the red it is vivid, in the green it is black. Why? (*c*) Take a green ribbon likewise. In the green it is brilliant, in the red it is quenched.

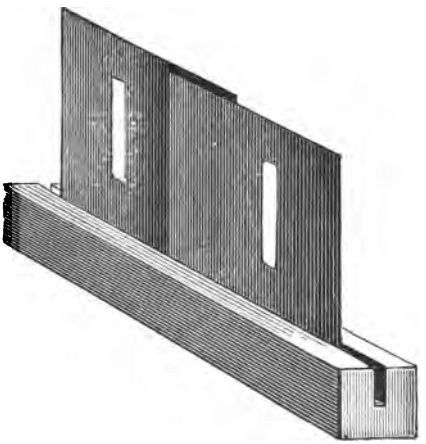

FIG. 164.

II. With a second prism of the same kind placed behind the first, edge to base, repeat Newton's experiment of recombining the spectral colours into an image of the source of light.

III. With the third prism repeat also the experiment shown in Fig. 32.

CHAPTER IX

77. 36. Instead of holding the card in the hand, we may adopt the arrangement shown in Fig. 164, which represents two black cards, each having a central slit ($1 \times \frac{1}{8}$ inch), adjusted as desired, by sliding in a groove, *e.g.* strip of slate-frame or of blackened wood across which the saw has been drawn. They may be used to show that for any colour in the spectrum there is a corresponding colour, which, added to it, will

produce white, *e.g.* blue and yellow. But note that the white *is very much feebler* than that *of all-coloured light.*

78. 37. The reflection tube will also be found in Home Experiment 135.

Chapter X

80. 38. *Multiple Images.*—The images are produced by the reverberation of the light from surface to surface of the glass. At every return from the silvered surface a portion of the light quits the glass and reaches the eye, forming an image. A portion is also refracted to the silvered surface, whence it is again reflected. Part of this reflected beam also reaches the eye and yields another image. This process continues, the quantity of light reaching the eye growing gradually less, and as a consequence the successive images growing dimmer, until finally they become too dim to be visible.

84. 38*a*. The principle of *Reversibility* which runs right through optics comes into play. The rays go and come back by the same route. They return to the source of light—here, the candle.

Chapter XI

92. 39. These Bengal lights are not *pure red*, but they answer the purpose.

94. 40. *Spectres.*—The objective is removed, and a black card with a circular aperture is held in front of the lantern nozzle. A loose focussing lens is used to project the image of the aperture on the screen, say a disc of 18 to 24 inches. A piece of coloured glass is then held against the blackened card for half a minute; the cap is then put on the nozzle, and the gas turned up.

After trying the effect of single colours, the spectrum through the carbon bi-sulphide prism and a rather *wide* slit is projected by the same method. When the gas is turned up the complementary spectrum appears on the screen.

40*a*. "Helmholtz has revealed the cause of the green produced y a mixture of blue and yellow pigments. No natural colour

is *pure*. A blue liquid or a blue powder permits not only the blue to pass through it, but a portion of the adjacent green. A yellow powder is transparent not only to the yellow light, but also in part to the adjacent green. Now when blue and yellow are mixed together, the blue cuts off the yellow, the orange, and the red ; the yellow, on the other hand, cuts off the violet, the indigo, and the blue. Green is the only colour to which both are transparent, and the consequence is that when light falls on a mixture of yellow and blue powders the green alone is sent back to the eye." This may be proved by sending a beam through an ammoniacal solution of copper sulphate, which transmits a fine blue with a large portion of green, and a yellow solution of picric acid, which also allows the green to pass.

97. 40*b*. Conversely, the ghost effect is produced by gazing at a silhouette figure in flowing robes, after which a white figure will appear floating in the air.

CHAPTERS XII AND XIII

99-113. 41. *Lenses* divide themselves into two classes. Those which are *thickest* in the middle and render parallel rays *convergent*. Of these the *double convex* is the type ; the modifications are the plano-convex, which may be regarded as half of the former, and the meniscus or crescent.

42. Those which are *thinnest* in the middle and render parallel rays *divergent*. Of these the *double concave* is the type ; the modifications are similarly the plano-concave, and diverging meniscus, in which the concave surface is most strongly curved.

43. A straight line drawn through the centre of the lens, and perpendicular to its two convex surfaces, is the *principal axis* of the lens. A ray of light travelling along this line is not refracted.

44. If a *beam* of light be incident on a *convex* lens parallel with the principal axis, its constituent rays cross at a point on the axis produced behind the lens. This point is spoken of in the text as *the focus*, which means the focus for *sunbeams* or

parallel rays. It is the *principal focus*. With other than parallel rays we may have an infinite number of foci.

45. Conversely the rays from a luminous *point* placed in the focus are rendered parallel after passing through the lens.

46. The rays from a luminous *point* placed *beyond* the focus cross somewhere on the other side of the lens, and here an image of the source is produced (as in Chapter I.)

47. As the point draws towards the principal focus, the place of crossing (and therefore the image) moves further and further off, until when the point is actually *in the focus* the rays *do not cross*, or cross at infinite distance, which is practically the same.

48. The image of an object at (practically) infinite distance, viz. the sun, is formed at the principal focus. Conversely, the point (image of sun) in the principal focus has its original at infinite distance. Continuing to approach the lens, after passing the principal focus, there still is *no image* formed, because, instead of crossing, the rays *parallel* in the last instance, now begin to widen out or *diverge* after passing through the lens. It is well to draw the paths of the rays on paper. Producing these *diverging rays backwards* they will cross beyond the luminous point, forming in the air what is called a *virtual negative image*—one which cannot be received upon a screen.

49. A virtual image is always on the *same side* of the lens *as the object*; moreover, it is *erect*, since the rays do not cross after passing through the lens. This is the principle of the lens used as a *simple microscope*: a virtual, enlarged, and erect image of an object placed between the lens and its principal focus is seen on looking *through the lens* (Fig. 50).

50. When an object is placed anywhere *beyond the principal focus* a *real image* of the object is formed in the air behind the lens. The image may be either larger or smaller than the object, but is always *inverted*. This is the principle of *Optical Projection*. The *positions* of the image and the object are, as before, *exchangeable*. *The relative sizes of the image and the object are as their respective distances from the lens.*

51. If both are at the same distance from the lens, the image is of the same size as the object. This position will be found to be twice the focal distance (see Home Experiment 115).

52. *The Objective.*—As the whole art of Optical Projection depends upon the action of lenses, it is well to master the subject first by using a *single lens.* Admitting a beam of sunlight through a small hole in the shutter or blind, or from the lantern (without lenses), take a lens of the longest focus you have, *i.e. the flattest,* and having heated the end of a stick of sealing-wax, push the lens into it for a handle. Now hold it *near* the wall opposite to the window whence the beam issues, and, by walking backwards or forwards, you will find a place for the lens, where a clear inverted image of the window and scenery outside will be pictured on the wall.

53. Finding the right position for the lens is called focussing. Take a lantern slide or a square of smoked glass with some figure upon it, and fixing it at various distances from the window, focus a sharp image on the screen. Take some microscopic object and project it in the same way. A slide or picture of any kind can be projected with single lens. A lens so used is called an *objective,* and must not be of *smaller* diameter than the hole in the blind.

54. *The Condenser.*—The smaller the object, the smaller and *rounder* the lens must be. That means, that the hole also must be smaller, or some rays will pass *over* instead of going *through* the lens, and will make a bright spot in the middle of the image. But as the focus is so short we must draw the screen very close, or the rays will spread themselves over such a large space that the picture will not be bright enough to be seen.

55. How can we make more light come in through the hole? We cannot. But by making a larger hole we can admit a larger beam, and cause it to pass through a lens the size of the hole. It will not only condense the rays so that *all of this larger beam* can pass through the little lens (objective), but will also *light up the object more brightly.*

56. In these experiments it is well to use touch-paper. Then a position can be found, after fixing the condenser, where the entire beam will pass *through* the object, and also through the objective beyond. This is clearly shown in the Solar Microscope (Fig. 54).

With a condenser and an objective of *very small* focus, such as those described in the text, very small insects can be projected an immense size on the screen.

57. *Practical Summary* (Prove with a candle, lens, and screen in darkened room).—Let f represent the focal length of the lens. Fix the lens in the middle of the room. Make a chalk line on the table or floor, and mark off the distances f and $2f$ (*twice the focal distance*).

58. Place the candle at some distance beyond $2f$. The screen must now be drawn up on the opposite side of and *near* to the lens, where a *real, inverted, and diminished image* of the flame will appear. As the candle approaches $2f$ so the image *grows, and recedes* from the lens until the candle occupies the position $2f$.

59. $2f$.—On reaching this point *the image is of exactly the same size as the object, and is situate as far behind the lens as the object is in front.* The image continues to grow and recede until the candle reaches the point f.

60. f.—The image is now altogether beyond screen distance. Therefore *no image appears*, for the rays are (practically) parallel.

61. Drawing the candle still nearer to the lens, *between f and the lens, no real image* is formed. But on going behind the lens, and looking through it at the candle-flame, we may see *a virtual image erect and enlarged.*

62. The results of the above experiments may also be summed up in the formula $\frac{1}{f} = \frac{1}{p'} - \frac{1}{p}$, where f represents the focal length of the lens, p the distance of the object in front of the lens, p' the distance of the image behind the lens. For convenience' sake, the object is supposed always to be placed on the right hand of the lens; also distances measured from that side of the lens are

reckoned *positive*, on the other side *negative*. The focus of a bi-convex lens, being on the same side as the image, is considered negative.

The magnification (linear) is directly as the distance from the lens, thus $\frac{I}{O}=\frac{p'}{p}$ where I and O denote respectively the size of image and object.

63. The micro. lenses of Home Experiments 24 and 26 (*b*) are of very high power. The focus of a water globule is at the distance beyond surface equal to half the diameter of the lens. Thus a globule half a line in diameter, or $\frac{1}{24}$ inch, will magnify an object 128 diameters. The lenses of Experiment 26 (*c*) are both object and instrument, because the back of the drop, which we referred to in speaking of the rainbow, acts as concave mirror, magnifying the images of the objects situate between itself and the focus. These images are still further enlarged by the front surface through which they are viewed. The objects obtained by the various infusions are each of a different kind. Those from pepper, for instance, are oblong, elliptical, and continually in motion, turning aside to allow their neighbours to pass, lengthening themselves out to pass through a narrow space. As the drop evaporates they retire to the middle.

64. *The compound Microscope* consists essentially of an object glass of very short focus, *e.g.* $\frac{1}{3}$ or $\frac{1}{2}$ inch, and an eye-piece of about 2 inches focus at a distance from it of about 6 or 8 inches. The object is placed a little outside the focus of the object glass. A real inverted magnified image is formed on the other side of the lens, and this image is further magnified by looking at it through the eye-piece. The distance of the eye from the eye-piece ought to be equal to the focal distance of the latter. The objective is then made to draw nearer to the slide until a certain point is reached, at which it appears to be considerably magnified, *e.g.* if the focal distance of the objective be $\frac{1}{3}$ inch, and the object be $\frac{3}{8}$ inch from it, the image will be formed at a distance of $5\frac{1}{3}$ inches. It will therefore be fourteen times as large as the object, for $64 : 4\frac{1}{2} :: 14 : 1$ nearly. If the focal distance of the eye-piece,

in the focus of which this image appears, be 2 inches, it will magnify it about four times more, $14 \times 4 = 56$ (diameters). By lengthening or shortening the tube the image may be further magnified or diminished.

65. The object to be examined is placed upon the stage (Fig. 53, *f*), and is brightly illuminated. If transparent, light is reflected through it by means of a mirror (*h*) placed below the stage, which stage has a central hole; if opaque, light is sent down upon it through the condenser (*i*).

66. In viewing extremely minute bodies it is well to have some *visible standard* for comparing magnitudes. Take a piece of the finest silver wire possible and roll it round a cylindrical nail a few inches in length. Look at it through a lens, to see if the winding be perfectly even and close. Suppose there are 520 turns in an inch; then by cutting up the wire into very little bits we provide ourselves with a delicate measure ($\frac{1}{520}$ inch), which we can scatter upon the slide among such small objects as blood corpuscles, for example.

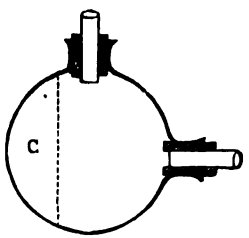

FIG. 165.

CHAPTER XIV

117-119. 67. *Fairy Fountain.*—(1) A tank similar to the refraction tank is best for this experiment; preferably the water should enter near the bottom, and if made to percolate through a grating just above the orifice, the column of water will be free —from currents.

(2) Or a two-necked glass receiver, costing about 10d., may be used. The necks should be as wide as possible.

They should each be capable of receiving a tube ($\frac{1}{2}$-inch diameter) fitted into a cork bored to receive it.

The portion C (Fig. 165) acts as a convex lens, and is pressed

into the lantern nozzle (C, Fig. 166), the objective being withdrawn. The rest of the globe is blackened. Cork the orifice A until wanted, and connect B with the water supply. D is a support for the receiver. Adjust the light so as to be condensed on the orifice A. Then fill the supply tank, focus the

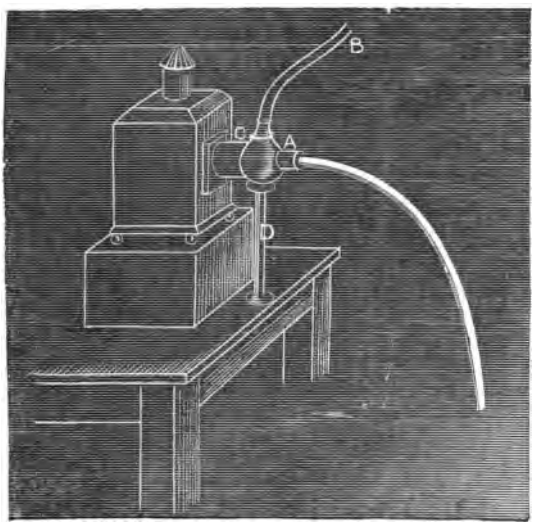

FIG. 166.

light upon the cork, then remove the latter and allow the water to flow into the bucket.

120. 68. *Total internal Reflection.*—Take small glass tube or bottle and put a roll of coloured paper inside. Place the tube *slant-wise* in a tumbler of water. You see distinctly the coloured paper in the tube by looking at it through the water. But now lower the tumbler and look *down* upon the water. The paper has vanished and the tube shines like silver.

69. Lift the tube up and down in the water: the paper vanishes and re-appears in a remarkable way.

70. Look *up* through the water at its under surface. You will see the coloured paper within the tube poised in the air above the water and *undiminished in brightness.*

Chapter XV

123-133. 71. I do not propose in these notes to discuss the merits and demerits of the various lanterns in the market; almost any lantern will answer for the majority of the experiments. If a lantern be specially bought for the purpose of illustrating these lectures, I would recommend the purchaser to find the nearest approach to the Solar Microscope.

72. The Sunshine lantern is a useful accessory to the Magic lantern, the latter being used to furnish a horizontal beam of light by withdrawing the objective and adjusting the source of light in the focus of the condenser.

73. A very good substitute for the Sunshine lantern may be extemporised by placing the glass basins on the rings of a retort-stand, with a swing mirror arranged under the larger lens. By this means several of the experiments described hereafter and in the Home Experiments may be performed, extempore diagrams made, etc.

74. Besides the methods given in Chapter XV slides for the Sunshine lantern may also be made thus: Flow photographer's transparent varnish on glass, and trace the design by cutting *nearly through* the varnish. By continued reflection from side to side of the scratch, the light is so weakened that the lines of the diagram actually appear *dark.*

75. Or, by using ground-glass varnish, the plate may be drawn upon with pencil or Indian ink, or may be *scratched through.* The slides are then coated with transparent varnish.

76. Or, draw upon thin sheets of mica with Indian ink rubbed up in water till quite thick.

77. Or, draw with a hard pencil on ground glass. Then n the glass and coat it with a mixture of two or three parts of

Canada balsam to one part of turpentine. Again warm the glass to drive off the turpentine. The Canada balsam flows into all the little hollows in the glass, making a clear, hard, transparent coating.

78. *Transferring Engravings.*—First coat the glass with photographer's dammar varnish or with Canada balsam. After some hours it will be in a viscous state. The engraving is now removed from a bath of rain water and laid carefully, face downwards, on the prepared surface, and is rolled or pressed in contact with the same, to exclude air-bubbles. Next day, if thoroughly dried, take a damp sponge or wetted finger and remove the paper from the back of the engraving. With a little care this can be done perfectly, then flow another coat of varnish over the surface to render it more transparent.

79. Soak the paper in a solution of potash and next in a solution of tartaric acid. By this means minute crystals of tartarate of potash become diffused through the texture of the unprinted part of the paper. As this salt resists oil, a roller charged with greasy ink can now be passed over the surface without transferring any of its contents excepting to the printed parts. Next wash and dry the print, after which the freshly deposited ink can be transferred to a paper or other surface by simple pressure in an ordinary hand press.

80. *Proofs of Wood-engravings on colourless transparent Gelatine.*—The gelatine employed is as thin as tissue-paper, and is identified by children as forming the transparent packets which envelop York confectionery. "The printer's ink," Mr. Lewis Wright says, "should be rather stiff and fine," a "hard" impression made, and the slides, he tells us, are "as good as photographs." The gelatine is, of course, bound between two thin cover glasses.

Chapters XVI to XVIII

134-163. 81. The lantern is somewhat at a discount in illustrating these three chapters as they stand. But should the

lanternist desire to go more fully into his subject, as he would be expected to do in addressing popular lectures to *adults*, he will find ample scope for the services of his lantern in *practical* illustration.

He would give a prefatory sketch of the solar system illustrated by slides. Nor would any account of King Sol be deemed complete without mention of sun-spots or of spectrum analysis in its application to the constitution of the heavenly bodies. He would refer to the lines of Frauenhofer and Kirchhoff's explanation of the same, the application of Kirchhoff's principles by Huggins, Miller, Secchi, Janssen, Lockyer, the brothers Henry, and others. In isolating this course he would also notice briefly the various effects of solar rays in heating, lighting, photography, fluorescence, phosphorescence, etc.; in fine, no honest character-sketch of King Sol could be given without passing in review the labours of his fairy helpers.

81*a*. To those who desire information on the former questions I would recommend three of the "Manchester Science Lectures" (Heywood, 1d.)—viz. "Spectrum Analysis," by Roscoe; "Spectrum Analysis in its Application to the Heavenly Bodies," by Huggins; "The Sun," by Norman Lockyer.

82. Earth receives less than a two-thousand-millionth part of the light and heat of the sun. "The sun's mean distance from the earth is 92,700,000 miles, his diameter is 865,000, and he rotates on his axis in a period between 25 and 26 days."

The weight of the sun expressed in tons is

2,154,106,580,000,000,000,000,000,000.

Were the earth of the same size, it would weigh nearly four times as much as the sun.

83. If we take a disc of white cardboard, 4 inches in diameter, and fix it vertically between ourself and the sun, on retiring almost 12 yards the sun will be exactly eclipsed. From this we may make the calculation: The diameter of the sun is to

the diameter of the cardboard disc as the distance of the sun is to the distance of the disc from the eye. When we know the distance we have thus a simple means of determining the dimensions.

84. "If we could build up a solid column of ice from the earth to the sun, two miles and a quarter in diameter, spanning the inconceivable abyss of 93,000,000 miles, and if then the sun should concentrate his power upon it, it would dissolve and melt, not in an hour, nor in a minute, but in a single second: one swing of the pendulum, and it would be water; seven more, and it would be dissipated in vapour."—*Professor Young.*

85. Sir J. Herschel's miniature solar system is somewhat too extensive for a Home Experiment. He says "Choose any well-levelled field or bowling-green, and on it place a globe 2 feet in diameter; this will represent the sun." The relative sizes and distances of the members of the solar system are as given below:—

PLANETS, ETC.	OBJECTS TO REPRESENT THEM.	REPRESENTATION OF DISTANCE FROM THE SUN.
The Sun . . .	A globe 2 ft. in diameter.	
1. **Mercury** . .	A grain of mustard seed.	Revolving in a circle 164 feet in diameter.
2. **Venus** . . .	A small pea . . .	284 feet ,, ,,
3. **Earth** . . .	A pea	430 feet ,, ,,
4. **Mars** . . .	A large pin-head . .	654 feet ,, ,,
(**The Asteroids**) .	Grains of sand . .	1000 to 1200 feet ,,
5. **Jupiter** . .	A moderate-sized orange	½ mile ,, ,,
6. **Saturn** . .	A small orange . .	¾ mile ,, ,,
7. **Uranus** . .	A full-sized cherry . .	1½ mile ,, ,,
8. **Neptune** . .	A good-sized plum . .	2¾ miles ,, ,,
The Nearest Fixed Star . . .	. . . . .	18,000 miles.

135. 86. Fig. 63 represents King Sol in a somewhat different aspect from that in which he is ordinarily visible to the dwellers on earth. The central disc, with which we are so familiar, is surrounded by a halo or crown (*corona*) of glory. This corona is on ordinary occasions quite overpowered by the brilliance of the central portion (*photosphere*), to which we owe most of our

light. Even when the sun is partially eclipsed the corona is unseen. But directly the moon's dark face completely hides that of the sun, that instant, the pearly cones of light gleam forth with a radiance equal to that of the moon on a bright moonlight night. This everchanging halo of light is believed to be in constant attendance upon King Sol, and is evidently composed of very unsubstantial materials. This beautiful drawing of the corona has the merit of being correct. It was made at Mantawalock, Kekee, during the total eclipse of August 1868.

87. The professors of the College of Manilla, desiring to photograph the corona, but finding the task hopeless, prepared a number of sheets of paper which were introduced in rotation into a darkened chamber, and as the image of the eclipsed sun fell upon each, the features of the corona were rapidly sketched in by hand. Observe the curved streak of intensely white and uniform light crossing the longest of the coronal beams. Notice also, nearer to the photosphere, the local juttings of the sun's atmospheric envelope. Seen during solar eclipse these prominences or "leaping flames" (elsewhere referred to) are *red.*

148. 88. Fig. 67. This globe also forms the simplest of all sundials. It is merely necessary to divide the equator into twenty-four equal parts to represent the hours, and incline the globe to an angle equal to the latitude of the place, or, what is simpler, cause the hour circle to make this angle with the equator. The focus of such a glass globe filled with water is at a distance beyond its surface equal to half the diameter of the globe.

150. 89. *Half-crown Experiment.*—This experiment is masked by an illusion, not so apparent to young children as to adults. Theoretically, we estimate of the size of objects by the space occupied by their images upon the retina. Practically, when dealing with familiar objects our reasoning faculties also come into play. We compare the object with other known objects in its vicinity.

153. 90. Fig. 68. The screen is thus prepared. Take a large eet of blotting-paper or drawing-paper—bank-post is better

than either. Lay on the middle of it a piece of paraffine-wax as large as a pea. Approach the under side of the paper with a hot iron. When the wax has melted and spread over a large area, turn the paper over, place a similar piece of wax on the centre of this side, and proceed as before. Repeat the process, alternating the sides of the paper until a disc of the required size is obtained.

158. 91. *Pin-hole Magnifier.*—The reason why the object cannot ordinarily be seen when held so near to the eye, is that the rays proceeding from each of its points and falling upon the pupil do not converge to a point, as when the object is at a proper distance. The image of each point is a small circle; and as the small circles produced by the different points of the object encroach on each other, all distinction is destroyed. But when we employ the pin-hole each pencil of rays has the same diameter as that of the hole.

92. We have learned how a pure spectrum is obtained, and that a second prism is unable further to decompose the light. Newton found that the second prism merely *spread out* the colour-bands still further. When a solar beam is thus sent through more than one prism, there are found to be blanks in the spectrum—spaces where *no light* reaches the screen. These dark gaps correspond with, and mark the *absence* of certain colour-rays from sunshine.

93. When gaslight, limelight, or electric light is employed there are no gaps, but an unbroken rainbow band from red to violet.

94. These dark spaces in the solar spectrum were long a puzzle to philosophers. Frauenhofer lettered them, made accurate maps of them, and studied long, how to account for the missing rays. Thus they have been named *Frauenhofer's lines.*

95. The explanation is due to Kirchhoff. It is that *every body is specially opaque to such rays as it can itself emit, when rendered incandescent.*

96. This can be observed best in reference to the line D.

Employing the flame of a spirit-lamp with a salted wick, instead of sunshine, the well-known bright yellow line indicating *sodium* appears on the screen. Substituting gas or lime-light, a continuous spectrum is formed; on interposing the salted lamp-flame in the path of the rays, the yellow rays are cut out, and we have instead a dark band of the same width, and in the same position as the yellow occupied.

97. Introducing other flames in the same manner, in the path of the beam, if the quantity of metallic vapour in the flame be sufficient, each flame will cut out its own bands. And if the flame through which the light passes, contain the vapours of several metals, each will present its own characteristic dark band upon the screen.

98. What would occur if the lime-light were as large as the sun, and wrapped round with an atmosphere of flame? The surrounding flame would cut out those rays of the globe which it can itself emit, and present gaps in the spectrum.

Thus we are led to regard the sun as a solid or molten nucleus, highly incandescent, surrounded by a flaming atmosphere of vapours absorbing all those colour-rays of the central mass which they themselves emit.

99. Could we examine separately the spectrum of this surrounding flame on a dark screen, we should observe a series of *bright bands* as produced by metallic vapours.

100. As a crucial test, admit a sunbeam and light from the sodium flame through the same slit, and on to the same prism.

Chapters XIX and XX

164-179. 101. *How the Sunbeams feed the Flowers.*—It is not precisely known by what chemical action the oxygen is separated from the carbon by the plant *in the presence of light.* It is supposed by some writers to be owing to the presence in chlorophyll of a trace of iron, which, under slightly altered conditions, unites with a greater or smaller proportion of oxygen. In the

latter case oxygen is liberated. Chlorophyll is never formed unless iron be present.

102. If some seeds be sown in a pot and placed in a dark cellar, slender stalks arise, carrying a pair of seedling leaves, *yellow* instead of green. The stalks grow longer and longer, thin, white, and watery, so feeble that they cannot support their own weight. They fall over, and the little plants die.

103. But if, the seeds having germinated, the pot be carried into the open air, the yellow seedling leaves soon become green and healthy.

104. Sir William Siemens sowed three pots with mustard seed. (*a*) he grew in the ordinary way ; (*b*) was kept in darkness during the day and exposed to the electric light at night ; (*c*) had daylight during the day and electric light at night. (*a*) and (*b*) looked very much alike, but (*c*) was much hardier, yet not so tall, and had very large dark green leaves. This will account for the rapid growth of plants in summer in the Arctic regions, where the sun is above the horizon the whole of the day.

105. It was found by Dr. John Draper that the two processes, viz. the liberation of oxygen and the restoration of the yellow seedling leaves, were most vigorously carried on in the *greenish-yellow* rays of the spectrum, and decreased on either side, and that the blue and violet rays had little or no effect. Dr. Draper admitted the sunlight through a prism fixed in the shutter. It is highly probable that the process which liberates the oxygen also forms the chlorophyll.

106. Still more remarkable than the liberation of oxygen or of the restoration of the *etiolated* plant, is the action of sunshine in discharging the green coloration from chlorophyll, either in solution or in the grains themselves. This leads us to think that the green matter constantly present represents rather a halfway product in the formation of the organic compounds of which the plant is built up, and that probably the process

which results in the formation of the green constituents and that by which the colour is discharged are carried on *simultaneously.*

107. Chlorophyll is known to be a mixture consisting mainly of three colouring matters—(*a*) *blue chlorophyll,* bluish green, known by its red fluorescence (see Chapter XXXVI); (*b*) *yellow chlorophyll,* greenish yellow very similar in its action, yet quite distinct; and (*c*) *xanthophyll,* not fluorescent, but known by its stopping out the blue rays from the spectrum. This mixture is present in all land plants (except fungi and one or two parasites), but not in all parts of a plant. Thus in variegated plants the green bodies are almost entirely absent from the yellow portions, and entirely absent from the white, while in red cabbage they are masked by red colouring matter, soluble in water, which, when discharged, shows the cabbage green as ordinary leaves.

108. Only the green parts of plants decompose the carbon di-oxide. The other parts, *e.g.* flowers, roots, fruit, etc., act otherwise on the air; they breathe exactly as animals do. The action of the green parts is rather that of *digestion* than respiration, and *is only possible in sunshine.* The plant feeds on the carbon which it separates, just as animals feed on the carbon contained in their food.

109. The breathing and digesting processes go on simultaneously in the daytime, but the latter is much more *actively* carried on. The green parts remain *inactive during darkness,* but the breathing *always* goes on. In winter, when plants have lost their leaves and green parts, they live on the store of carbon laid in during the summer.

171. 110. Only a very small quantity of mercury oxide is to be used, just enough to cover the bottom of the tube, say to rise $\frac{1}{8}$ inch. Beginners always take too much. The same remark applies to the lime-water. Hold the bottles side by side.

175. 111. *Stomata.*—If the under skin of almost any leaf be peeled off and placed under a microscope, stomata will be found;

but when an aquatic plant floats on water, the mouths are only found on the upper surface. These are the chief feeding-places of the plant. Here the carbon is united into various compounds, resulting in the wood of the tree, the starch of the potato, or sugary matter of beet, carrot, parsnip, and sugar-cane, and honey of the nectary of flowers. Stomata are large on soft, pulpy leaves, and small on hard, leathery ones.

CHAPTERS XXI AND XXII

112. *Accommodation.*—The healthy eye when at rest sees *distant* objects distinctly by the contraction of the *ciliary muscle*, which regulates the tension of the plaited ruff (*ciliary body of Zinn*, *z*, *z*, Fig. 79). The elastic lens, but chiefly its front surface, becomes more convex, and therefore more refractive, enabling the images of *near* objects to be focussed *on the retina.* Elderly people lose this power of accommodation in a degree, and to supply the deficiency they place a convex lens in front of each eye. In children the cornea is sometimes too round. The image is then focussed *in front of* the retina. To obviate this *concave* glasses are used. This defect is somewhat compensated for, when the tissues have lost the elasticity of youth, then normal vision is restored, and spectacles are dispensed with. Long and short sight can be illustrated by means of the model eye and a hand screen.

113. *Retina.*—The optic nerve (*o*, Fig. 80), a cylindrical cord containing a multitude of nerve-fibres enclosed in a strong sheath of tendon, enters the eye from behind, not quite centrally, but rather nearer to the nose. These fibres spread out in all directions over the front of the retina, and terminate, first, in two layers of nerve-cells, similar to those found in the brain, and *behind* these in what is really *the sensitive layer*, a mosaic of closely-packed *rods and cones* resting upon the blackened lining. Each rod is a slender cylinder connected with one of the minutest nerve-fibres. The cones are club-like structures, some-

what thicker than the cylinders, and are connected with nerve-fibres less minute.

114. *Fovea centralis.*—The retina is somewhat thickened in the *yellow spot* (*ml.*, Fig. 80), and in its centre is a small pit (*fovea centralis*), the spot where the most exact discrimination of distances is made. Here the cones measure only $\frac{1}{10000}$ part of an inch, and are most densely packed; moreover, from their central position they receive *direct* light. According to Helmholtz, "a single nervous fibril runs from each of these cones through the trunk of the optic nerve to the brain without touching its neighbours, and there produces its special impression, so that the excitation of each individual cone will produce a distinct and separate effect on the sense."

115. So distinct and accurate is vision in the central pit, that here we can distinguish the distance between two points *one minute* apart. This angular distance represents, in the field of vision, a space covered by $\frac{1}{60}$ part of the diameter of the nail of one's forefinger when stretched out as far as possible.

116. But the screen of "our own camera" is less than an inch in diameter (10·9 lines accurately), and the distance apart of the said points corresponds, on this screen, with the width of one of the cones, $\frac{1}{10000}$ inch.

117. When we *look at* an object, we place our eye in such a position, that its image shall fall on the yellow spot. Although this space corresponds with an angular distance of only one degree, and can be blotted out by the forefinger nail of the extended hand, we see *indirectly* the surroundings of the picture, especially any striking object; and the defects due to inexactness of vision, the retinal shadows, gaps, and sparsity of cones in other parts of the retina are fully made up for, in the marvellous rapidity with which we can turn the eye from one point to another, and thus see minutely detail after detail in the field of vision.

118. It is chiefly due to this power of moving the eyeball, and at the same time altering the accommodation as we look

upwards, downwards, to the right, or to the left, that the eye has no rival among optical instruments.

119. Although neither the photographic camera nor the eye can show *near and distant* objects distinctly, yet the latter shows each detail in such rapid succession that most people are unaware of the fact.

120. *Iris.*—The iris, a broad muscular ring, owes its action to two sets of fibres, which by their contraction enlarge or diminish the pupil respectively. The latter are arranged circularly round the aperture, the former radiate thence to the circumference.

121. *Bodies seen within the Eye.*—Besides the fibres and spots in the lens which cast shadows when we view any uniformly bright surface (*e.g.* when we look out of the top panes of the window or on to a beam of light), there are others which float about in the vitreous humour, and are seen when they come near enough to the retina. These minute fibres, corpuscles, and folds of membrane are present in all eyes, though they usually float to the top of the globe, out of the field of vision, until some sudden movement of the eye dislodges them. They are called *muscæ volitantes*, "flying insects" (Fig. 168), because when we try to look at them, the movement of the eye disturbs them, and they escape us. If the pupil were a mere pin-hole in diameter, these bodies would cast sharp shadows on the retina and cause much annoyance. Ordinarily, however, they are little noticed, owing to the diameter of the pupil. The shadows are practically *washed out.*

121*a*. *Astigmatism* is present in some degree in most human eyes, and prevents our seeing vertical and horizontal lines with equal clearness at the same moment (Home Experiment 150). It is due to the fact that the cornea of most eyes is not a true symmetrical curve, and to inaccurate centering of the cornea and crystalline lens combined. Cylindrical glasses are used when the defect is excessive.

122. *Irradiation.*—The image of a point of light—a star,

for instance,—brought to a focus on the retina is far from being accurate. The rays which we see round stars and distant lights are in reality *images of the radiated structure of the crystalline lens*, the fibres of which are arranged round six diverging axes. "Star-shaped" we call a figure with diverging rays, and the word is proof that this defect is common to everybody's eyes.

123. *Chromatic Aberration.*—If a beam of all-coloured light be passed through a bi-convex lens of any transparent substance known, the colour-rays, being unequally refracted, will not all be brought to a focus in the same point. Therefore the size and position of the optical images thrown by the different colour-rays are not quite the same; *they do not perfectly coincide in the field of vision.* The violet rays, being more refracted, intersect before the red. Placing a screen at any point in the convergent beam up to the violet focus, we obtain a disc bordered with orange to red—the rays not yet converged; farther off, at the red focus, we have a disc similarly bordered with blue to violet rays, now divergent. The reason of this is evident: a section of such a lens (Fig. 45) shows that it may be regarded as composed of two prisms placed base to base.

124. The human eye is not entirely free from chromatic aberration, though there is somewhat less than a similar glass instrument would have, owing to the fact that the interior of the eye is mainly water, which possesses a lower dispersive power than glass. An eye constructed to bring red light from *infinite distance* to a focus on the retina, can only focus violet rays on the same from a source two feet distant. This defect is little noticed, because the images produced by the brighter colour-rays, yellow, green, and blue, being so much more intense, mask those of the extreme rays.

125. But when we look at a flame through violet glass, which isolates these rays (Home Experiment 45, *b*), the effect is very striking. Glass coloured with cobalt oxide transmits red and blue rays, but stops the brightest rays—green and yellow.

On looking at the flame from a great distance—speaking for my own eyes—I see a red light, not so bright as from the red bull's-eye in the tram car at the same distance, but more like the end of a cigar. On approaching, the red fades into bright pink, and finally into a pink shot with pale blue (as in stereoscopic combination). So far for the *nucleus*. The *corona* is not seen at first. When it comes in sight it is almost white, and I have seen it not unlike Fig. 63. It then grows more tinted, and finally the whitish light shades into faint blue with a narrow border of very bright blue. Outside this is a broad band of deeper blue tinged with violet. This is the dispersive image of the flame thrown by its blue and violet light, and establishes a simple and complete proof of the chromatic aberration of the eye. The amount of dispersion varies even with the same individual, sometimes being practically nil, at other times very considerable.

126. The pupil appears black, not only on account of the black lining, but because the rays, after having lit up the interior, return upon the source of light. They go and return by the same route. This explains why we do not see into a room from the street, unless it is lighted up within. Also why we do not see out of the window, when holding a candle between the window-pane and our eyes.

The Stereoscope

127. Leonardo da Vinci, a Florentine, was the first to point out that the views of the outer world presented to each of our eyes are not precisely the same. Each eye sees a perspective view of the objects which lie before it; but inasmuch as it occupies a somewhat different position in space from the other, its point of view, and therefore its whole perspective image, is different.

128. In Wheatstone's original stereoscope (Fig. 145) the observer looks with the left eye into the mirror M, and with the right into the mirror M'. Both mirrors are placed at an angle to the observer's line of sight, and the two pictures are so placed

at A and A′ that their reflected images *appear at the same place* behind the mirrors, but, as will be seen from Fig. 145, actually the right eye sees the picture A′ in the mirror M′, and the left sees the picture A in the mirror M. This stereoscope, although not so convenient as that of Brewster (Fig. 82), gives greater *sharpness* of definition. An ordinary stereoscopic slide is cut in two, and half placed in each end of this instrument.

129. But the stereoscope is not at all necessary in order to combine the two images on a stereoscopic slide into one image; its use is simply to *guide the eyes* so that each of them shall at the same moment look at "identical points" in the two views. A card, or even a pencil point, placed between the eyes is in many cases quite sufficient, but for the use of children I recommend the stereoscope without lenses (Home Experiment 155). (The main use of the lens is to bring the image *nearer*, and thus practically to shorten the box.) The principle of construction is simple: each eye sees only the picture which belongs to it, because the distance ($2\frac{1}{2}$ inches) between the eyes is normal; moreover, it sees that picture at the distance of distinct vision or normal focus (11 inches).

130. Carrying out these theoretical considerations a step further, it seems to me that a photograph taken by such a camera through apertures $\frac{1}{16}$ inch diameter would give almost as near an approximation to the *natural conditions* as is attainable. I have not tried it. The camera would have to be rather inconveniently long ($22\frac{1}{2}$ feet). Practically the same effect would be obtained through apertures $\frac{1}{50}$ to $\frac{3}{100}$ inch and a screen distance not exceeding 15 inches; but since this aperture is less than the average diameter of the pupil, there would be some magnification, compared with the retinal image of the natural scene presented to the eye.

131. Home Experiment 43 illustrates how the scene changes with the point of view. Let us now suppose the walls to approach each other within a distance of about 3 inches. On repeating the experiment the same phenomena would result, or

we might stand at the top of the street and look down, closing the eyes alternately. Then we should be convinced of the somewhat paradoxical statement descriptive of the stereoscopic slide, viz. that the right eye sees further to the left, and the left eye further to the right. This is also the case in viewing interiors, but if the object be *convex and very near*, then we see more of the right side with the right eye, and of the left with the left eye. But we must distinguish between individual objects actually present before us, and a stereoscopic slide. And this is the distinction. The objects on a stereoscopic slide are all in the same vertical plane, as they would appear if traced upon a window, darkly draped, between themselves and us. When the pictures are correctly mounted—a circumstance somewhat rare —the illusion is perfected by the relief afforded by the mount, which appears nearer to the observer than the scene itself.

132. In looking at and combining two such pictures, the eyes *go through the same process*, and therefore receive the same impression as when they look at the *real* object. For the distances between "identical points" vary in different parts of the picture (Fig. 83, Experiment I.) Therefore different degrees of convergence of the lines of vision are necessary to combine the pairs of points. In other words, the crystalline lens must alter its curvative, making itself rounder in order to combine identical points in the foreground, and flatter for identical points in the distance, just as in viewing the real scene. From this it is evident, that, neither in Nature, nor in a stereoscopic slide can the *whole view* be seen in relief at any one time, but only those points which are the same distance from the eye. The others are seen *blurred*. It has been explained by Johannes Müller that "for each point of one retina there is on the other a *corresponding* point." The "corresponding points" of Müller are those which are situate at the same lateral and vertical distance from the centre of the "yellow spot."

133. The two retinal images of a *flat picture* are identical, and unite into a single image. Thus when two impressions are

taken from the same type or copper-plate and placed in the stereoscope they coincide line for line. If we place an original and a copy side by side, the lines, not being *identical*, will not be superposed, for no human skill can make a *perfect* copy. This method, which is adopted in testing suspicious bank notes, proves conclusively how "vivid, sure, and minute is our judgment as to *depth* derived from the combination of the two retinal images."

134. A stereo slide, one half of which is drawn in black lines on a white ground, the other in white lines on a black ground, instead of combining into a grey, presents a kind of metallic lustre, varying in shade with the amount of illumination of the whole, as well as with the degree of *attention* of each eye, from that of shining coal to that of the street flags on a sunny day. The points where black and white lines coincide appear clear as crystal. In *photographs* (a positive and a negative) the effect is that of shining silver, or of calm water, or of the gloss of leaves.

135. If the object be correctly cut out in black and white paper and mounted stereoscopically on a medium coloured card, it appears *luminous* rather than shiny, as though the object were lit up from within—a kind of Chinese lantern effect.

CHAPTER XXV

213-218. 136. Fig. 94 is an ideal picture of a forest of the coal period, drawn from data supplied by fossils. Each bed of coal rests upon a layer of shale known as the *under-clay*. In these under-clays alone, are found bodies known as *stigmariæ*, since they possessed *stigmata*, *i.e.* diamond-shaped *marks* or pits. The stigmaria has long been a puzzle to geologists. From the researches of Professor Williamson, it would seem not improbable that the stigmaria passes upwards into the fluted tree-stems of the *sigillaria* with its seal-like leaf scars—in fine (1) that the stigmaria is the root of the sigillaria, (2) that the under-clay represents the bed of an ancient forest, and (3) that the character-stigmata are points from which *rootlets* have been given off.

CHAPTER XXVI

219-223. 137. *Newton's Rings.*—Knowing the radius of curvature of the lens and the diameter of the rings, Newton calculated the thickness of the layer of air where each colour was produced. Observing similar colours, and finally a circle of black in the soap-bubble, he concluded that the films of water in the bubble, and of air on the glass plate, were of equal thickness where the same colour appeared on each.

138. *Newton's Rings.*—Newton thus describes the phenomena in the second book of his *Optics*: "Obs. 17. If a bubble be blown with water first made tenacious by dissolving a little soap in it, it is a common observation that after a while it will appear tinged with a variety of colours. To defend these bubbles from being agitated by the external air (whereby their colours are irregularly moved one among another, so that no accurate observation can be made of them), as soon as I had blown any of them I covered it with a clear glass, and by that means its colours emerged in a very regular order, like so many concentric rings encompassing the top of the bubble. And as the bubble grew thinner by the continual subsiding of the water, these rings dilated slowly and overspread the whole bubble, descending in order to the bottom of it, where they vanished successively. In the meanwhile, after all the colours were emerged at the top, there grew in the centre of the rings a small round black spot, like that in the first observation, which continually dilated itself till it became sometimes more than one-half or three-quarters of an inch in breadth before the bubble broke. At first I thought there had been no light reflected from the water in that place; but observing it more curiously, I saw within it several smaller round spots, which appeared much smaller and darker than the rest, whereby I knew that there was some reflection at the other places which were not so dark as those spots. And by further trial I found that I could see the images of some things (as of a candle or the sun) very

faintly reflected, not only from the great black spot, but from the little darker spots which were within it.

"Obs. 18. If the water was not very tenacious, the black spots would break forth in the white without any sensible intervention of the blue. And sometimes they would break forth within the precedent yellow, or red, or perhaps within the blue of the second order, before the intermediate colours had time to display themselves."

139. *Iridescent Films* (*permanent*).—If a solution of bitumen and a little indiarubber in a mixture of benzene and oil of naphtha be dropped on water, it will form iridescent films, which solidify and may be caused to adhere to a sheet of paper.

140. *Reade's Iriscope* is held in a clip, and focussed in exactly the same manner as the soap film (Fig. 102). The black paper must be pasted on to the back of the plate. The alum cell should be placed in the lantern, as the iridescent effect is entirely due to the *condensation* of the water vapour of the breath.

141. *Rings.*—The rings are sufficiently described in the text. Rings 1, 2, and 3 inches in diameter are found to be the most convenient sizes. At home children can make very fair rings out of hair-pins, in lieu of better material. If the rings cannot be soldered, make a loop of fine aluminium wire, join and twist the wire several times to form a handle like a toasting-fork. The circle must be *quite* closed, without any lump at the joint. The wire should not be too thick or too smooth, nor should it be dipped in paraffine as is sometimes recommended; on the contrary, a deposit of rust is a decided advantage. Use the thinnest and lightest wire that will support the bubbles. All rings, trays, saucers, glasses, etc., mentioned must be first wetted with solution before a bubble is placed thereon.

235. 142. *Projected Films.*—Fig. 102 shows the arrangement for projecting the film. At A the film is held in the clip, as recommended in C, Fig. 101; the face of the film is exactly opposite to, and at the same height as the lantern nozzle. Now turn the lantern round until it is *parallel with*, not opposite to, the screen.

Paint a film over the ring, or dip it in the saucer without altering the adjustment. The image is then focussed on the screen by the loose lens F. It may be necessary to use the alum cell.

236. 143. In Fig. 103 the dotted lines show the form which the film assumes during the blowing.

238. 144. Bubbles float on carbon di-oxide. Strew some chalk over the bottom of a bowl or tub, and over it pour a little strong vinegar or hydrochloric acid. The heavy gas carbon di-oxide will be liberated, and will buoy up the bubbles blown on to it, in a very curious way. Children are apt to hold their heads over the bowl. To remedy this place it on the floor. The gas is not *poisonous*, but produces heaviness, drowsiness, and asphyxia when present in large proportions.

239. 145. (Fig. 106) Now draw the thread right off. The film entirely covers the ring.

240. 146. *Pipes.*—(*a*) The short clay pipe shown in the illustration is found in practice to answer better than any other for all ordinary bubbles, the pipe being first thoroughly saturated with the solution.

(*b*) For large bubbles a short-stemmed "show" pipe, such as navvies buy to hold an ounce of tobacco, is used. It may be attached to the house bellows if preferred.

(*c*) A *short* rather wide pipe is best for the bubble, which blows out the candle. A *small* filter funnel answers admirably. The stem of the funnel ought to be sufficiently long, but if not, add an inch of quill tubing as a mouthpiece, and connect by a mere joint of indiarubber tubing, so that the stem may be short and rigid. A small tin funnel does just as well.

(*d*) For the harmless balloons a special pipe is required. It is made by bending a portion of the stem of a long pipe (while the clay is wet) into the form WW. This bent portion is held over a spirit-lamp or Bunsen flame while the bubble is being blown.

(*e*) For the double and treble bubbles I much prefer the

method without the ring—the inside bubbles being put in by thrusting a finely drawn out and wetted tube horizontally through the bubble skin, *breathing* gently into it, then withdrawing the small pipe rather quickly. That is the whole secret, and ten minutes' practice will make the matter clearer than pages of description.

147. *Plateau's Soap Mixture.* — One part by weight of fresh-made oleate of soda is dissolved in forty parts of distilled water at a moderate heat. When the mixture has sunk nearly to the temperature of the room (which should not be lower than 68° Fahr.) it is filtered. Three volumes of this solution and two of Price's glycerine are poured into a flask and vigorously shaken for a long time. On the eighth day it is cooled in ice-water to 37° Fahr., and kept at this temperature for six hours. It is then filtered through very porous blotting-paper. A bottle of ice should be kept in the funnel, and the vessel which receives the filtrate should be packed with ice. The first portion is turbid, and must be poured back into the filter.

Test.—The bubbles should last eighteen hours supported on a horizontal ring in the open air.

147*a*. Mr. Lewis Wright recommends the following plan worked out successfully by Herr Dahne of Dresden :—

Keep in stock bottles, labelled : (*a*) Sodium Oleate (saturated solution), (*b*) Distilled Water, (*c*) Glycerine.

The solution (*a*) is made with distilled water, which can be obtained at the chemist's. The bottle must contain as much oleate as the water is able to dissolve. The solution is then tested (using litmus paper) as being free from acid or alkali. It is then filtered clear in the cold and kept in the dark.

The glycerine (*c*), Price's best, must be tested free from acid. The soap solution is then mixed as and when required thus :—

I. *A tough and lasting Film*, suitable for the pendulum, mill letter-balance, etc.—1 volume (*a*), 2 volumes (*b*), 1 volume (*c*). is mixture is apt to be streaky.

II. *Iris Colours, quickly succeeding each other*—1 volume (*a*), 4 volumes (*b*), $\frac{1}{4}$ volume (*c*).

III. *Iridescent, but vanishing Film*—1 volume (*a*), 5 volumes (*b*), trace of (*c*).

From these mixtures we learn that, the quantity of oleate being constant, glycerine toughens the film, and makes it *last*, by retarding evaporation. The "skin" of water, as we have seen, is more elastic, and thins out rapidly. Therefore if we want *rapidity* we add more water, *durability* more glycerine.

148. *Plateau's Experiments on the Rotation of a liquid Mass freed from the Action of Gravity.*—Plateau exercised the greatest care and nicety in his experiments, and they extended over a long period. Such painstaking as the record of his work reveals may not be within our power, but the experiment alluded to in the text was regarded by him as very easy of attainment—"mere scientific sport" he calls it. Therefore I shall describe his method, condensing as much as possible, and afterwards show within what limits it may be modified for our purpose.

149. *Tank.*—Plateau used a rectangular box (Fig. 117), formed of glass plates (10 × 8 inches) set in an iron frame. The axis was of iron wire $\frac{3}{50}$ inch thick, and carried an iron disc ($1\frac{2}{5}$ inch diameter) horizontally at its middle point. A hole drilled in the glass plate forming the bottom of the box admitted the lower end of the axis, and a small plate of iron cemented to the glass from beneath closed the hole. The upper end of the axis is screwed into a stouter wire, to which is affixed a winch handle. The square glass lid is pierced with two openings, each having an iron neck and stopper. The central aperture is $2\frac{1}{5}$ inches in diameter. The other, which should be near to it, is very little smaller, having also the neck less elevated. The central hole should bear a slight rim, so that, if necessary, by grasping this, the lid may be lifted off. Lastly, the glass plate, its edges having been ground, is cemented with putty into an iron frame turned up all round, so as to fit the box perfectly, forming an air-tight lid. The edges and metallic stoppers are

then oiled. A stop-cock, shown in the figure, completes the tank.

150. The central stopper is then lifted up, and a mixture of alcohol (not methylated) and water, having the former slightly in excess, is then poured in so as to partially fill the vessel. (Try nine volumes alcohol to seven of water.) A small quantity of mixture containing more water is cautiously added, which, being heavier, spreads itself in a horizontal layer over the bottom of the tank. A pipette or a fine glass tube is dipped into the oil, and, after closing the upper end with the finger, is drawn out and introduced into the tank by the finger now being withdrawn. The oil falls through the upper mixture and rests on the denser layer below, either in one or more isolated spheres. These may be united by introducing into one of the spheres the end of an iron wire, to which it will cling; the rod is then carried to a second, which is united with the first by *pushing the end of the wire through it also.* If the oil-sphere do not occupy the centre of the liquid, water or alcohol is added, as the case requires, and the liquid is cautiously stirred *a little* without dividing the mass of oil, and the system is left to rest. (Plateau's ordinary oil-sphere was nearly $2\frac{1}{2}$ inches in diameter, and was formed by successive additions of oil.) The disc, as well as its axis, having been well oiled, is slowly introduced into the liquid, and caused to penetrate by its edge into the sphere of oil. The sphere envelops the disc immediately.

151. *Experiment I.*—We slowly turn the handle, at first one turn in four or five seconds. Then increase to one turn in four seconds; then one turn in three seconds; now the flattening at the poles and the bulging at the equator is very well marked. We must not turn too long. The system must be left to repose after each trial.

152. *Experiment II.*—Begin by giving the handle two or three turns in a second. The liquid sphere becomes rapidly flatter at the poles, and develops into a form like a muffin, and becoming still thicker and more cushion-like at the edges, until

it is transformed into a perfectly regular ring, united to the disc by an extremely thin film of oil which fills all the space between them. Its diameter increases rapidly up to a certain limit; when this is reached the disc must be stopped. The same instant the film disappears, and the ring remains perfectly isolated, and has now a mean diameter of four inches. The ring of oil just before the rupture of the film presents a *very marked flattening.*

If, at the instant when the ring is well developed, we lift the disc completely up by means of the stopper which bears the axis, the mass of oil, formed by the return of the ring upon itself, continues to revolve for some time in the liquid, gradually becoming spherical.

153. *Experiment III.*—On substituting a disc of 2 inches diameter, and giving less than two turns per second, the ring separates into several isolated spheres, each revolving on its own axis in the same direction as that of the ring. Besides three or four large spheres, there are almost always three or four very small ones or satellites.

154. *Experiment IV.*—Then follows the experiment shown in Fig. 117. In order to increase the speed of rotation, Plateau found it necessary to use two pulleys, half an inch and 3 inches in diameter. The small pulley was fixed to the end of the axis, after removing the handle, the other probably at the edge of the tank. To this one he attached the handle. Lastly, the disc, instead of coinciding with the centre of the sphere, was placed almost beneath it. "In my system," says Plateau, "the velocity ought to be about $2\frac{1}{2}$ turns per second, which corresponds to nearly 15 turns of the disc in the same time." A ring is rapidly formed, united to the central mass by a thin pellicle. When the ring is sufficiently developed, the rotation is suddenly stopped. The pellicle then breaks, the ring remains completely isolated, and the central mass forms into a sphere.

155. Faraday coloured his oil green with oxide of copper, by

heating a little oil with the oxide, and then mingling that with the rest.

156. Unless a tank with plane sides or a globe be used for these experiments, we do not see the actual form which the oil assumes. Objects seen through cylindrical glasses are distorted. This may be proved by placing a marble in a tumbler of water, and viewing it through the glass.

157. The refraction tank may easily be adapted to these experiments by fixing the two pulleys on a lid of wood or metal. It is not necessary that the lid should be absolutely air-tight, the object being to check evaporation of the alcohol.

158. *Permanent Films.*—Skeleton frames, representing any of the regular geometric solids, serve to illustrate Plateau's laws. Those referred to in the text are selected on account of their extreme beauty of form. Beauty of colour is also represented in the iridescence of soap-films, but the fragile nature of these led Plateau, and others since his time, to devise some mixture which should give practically permanent films. We are indebted to Professor Silvanus Thompson for the solution of the problem.

159. Figs. 119-123 are copies of actual films made with Professor Silvanus Thompson's resin mixture. The frames are of brass wire, No. 30 B.W.G., soldered where necessary. The sides of the cube are about 1 inch long. The frames appear to be glazed with extremely thin glass, perfectly transparent, but having a very slight tinge of yellow.

160. Another form of great beauty is produced by dipping the equilateral tetrahedron, which results in a set of triangular films, having for their bases the wire edges of the skeleton frame, and having a common apex at its centre. On dipping the top triangle again, the enclosed air rises in a bubble, which finally assumes the form of a little convex-sided tetrahedron with liquid edges concentric with the form of the wire skeleton.

161. *Resin-film Solution* (*Thompson*).—Common resin, 46 °/₀; Canada balsam, 54 °/₀; spirits of turpentine—a few drops added after. The mixture must be heated in an oven or over a gas-flame

to just below the temperature of boiling water (95°-100° C.) Below this temperature the films are thick and clumsy; above, though more beautiful, they are too thin and fragile to last long, though films have been made at 110° C., but frequently these burst on solidifying. The frames are immersed for a sufficient time to heat the wires. After withdrawal, the films form, sometimes quite slowly, and last for an indefinite time.

Test.—So tough and strong are they, that a circular horizontal film (1½ inches diameter), on a ring made of iron wire ·035 inch diameter, supported on its centre a circular brass weight of 1 inch diameter, and weighing 1·765 oz. (50 grammes).

162. The points to be brought out in dealing with this subject are briefly these—I. The surface of a liquid is in a state of *tension*. II. The surfaces of liquids press on the liquids or air which they contain as an indiarubber ball presses on the air within it. III. The surface of a liquid is generally either more or less viscous than the interior.

163. I. This is illustrated by the threads in the rings, letter-balance, etc. It should also be shown that the *degree* of tension differs with the liquid. Thus the surface-tension of water is greater than that of the soap-solution or of alcohol. Why then does it not make good bubbles? Because the elements of strength in a bubble are *permanency and viscosity*. High tension tells against them.

164. Compare the surface-tensions of water and alcohol thus: Pour *a little* water in a china saucer; colour the water with a few drops of blue ink. Pour two or three drops of pure water in the centre; the surface just there is slightly less blue, that is all. But when a few drops of alcohol are poured on the same place, the water runs off with the alcohol on all sides, and heaps it up into a circular ridge or small crater until the centre of the saucer is quite dry. Or, paint a streak of alcohol across the saucer. The water draws back on each side of the alcohol line, forming a deep chasm.

165. Substituting for the alcohol, ether, which has a surface-

tension equal to three-fourths of the former, dip a brush into the ether, and hold it *near* the surface of the water. A hollow is formed, which follows the brush about, the furrow deepening as the brush is lowered towards the surface. This is due to the action of the vapour of ether. On inclining the tray, the coloured water, with a slight admixture of alcohol, flows down the ravine, first in hesitating single drops, and afterwards in a fine thread-like stream.

166. A striking experiment is to heat some resin on a tin saucer or plate, and allow it to cool. When this thin layer of resin is warmed by applying heat to any part of the plate, an ever-widening disc, clear of resin, is seen exactly, over the source of heat, showing that resin loses much of its surface-tension on being heated.

167. Further illustrate the subject by placing a drop of pure alcohol in contact with a drop of oil on a clean plate of glass. The alcohol will appear to chase the oil-drop all over the plate. The Home Experiments of floating camphor, the camphor boat, action of essential oils, etc., also a piece of lighted camphor floating on water, are all illustrations of currents set up at the frontier of two liquids possessing different surface-tensions.

168. Further, take a small wooden boat and wet the stern with alcohol or ether. (Suitable boats for this experiment are the tiny models made about an inch long, and sold for 3d. or 4d. each.) Launch this boat on water, and project its image with the lantern.

169. These experiments show very plainly the high surface-tension of water, higher, in fact, than any liquid (except mercury), *so that the water is always the energetic body*, waging warfare, and being victorious in every instance. Whatever is added to pure water *lessens the energy* of the film in that part.

170. When camphor floats on water it becomes slowly dissolved, and as quickly as the weaker spot is formed about the camphor, the surrounding water-film hurries off with this weaker film, until it is evenly distributed over the surface. This

explains the movement of the boats and of the alcohol drop.

171. If we decide to call the surface-tension or energy of the water-film 80, pure alcohol will be represented by 25, and ether 19. The surface-tension of pure water is 16·62 grains per square inch, and of a soap-bubble film is 4·63 grains per square inch. The latter may be proved by a very pretty experiment. Attach to the pipe-stem, by a joint of indiarubber, a bit of quill tubing bent at right angles (Fig. 167). Allow a bubble to blow itself out in water. The depression of the column within the immersed and transparent tube measures the pressure. It is a small fraction of an inch. The letter-balance also measures the pressure per unit area. It is an adaptation of an experiment first made by M. Dupré.

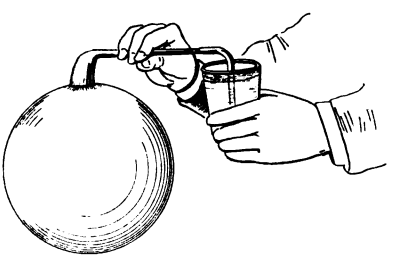

FIG. 167.

172. What is known as *capillarity* is a particular case of surface-tension. Space does not permit me to do justice to the subject, yet a word is necessary to clear the way for what follows. If a plate or rod of any substance be partially immersed in water, or in any fluid capable of moistening it, the surface of the fluid will rise to a higher level at the sides of the plate, as if the water were attracted by the plate or rod. But if a plate of glass be plunged into mercury, or if the glass be greased or rubbed with resin or lycopodium and plunged into water, a dint will be made in the liquid and *apparently* repulsion will take place.

173. Whenever two smooth perfectly clean flat surfaces of any substance, *e.g.* glass, lead, indiarubber, are pressed together, considerable force is required to separate them. When attraction

is exerted between the adjacent surfaces of *different* substances, *e.g.* a solid and a liquid, it is termed *adhesion*. Attraction between two portions of matter of the *same kind* is called *cohesion*. Thus if a plate be raised horizontally upwards through water considerable resistance is felt in separating it from the *surface* of the water. This is owing to the cohesion exerted between particles of the water *surface* and those of the *interior* of the liquid.

174. Similarly, if two small bodies capable of being wetted by water or other fluid in which they float, as two clean cork balls, be placed near together, they will *appear* to attract each other, being drawn together by united efforts of the cohesion of the fluid and its adhesion to the surfaces of the balls, and when the balls are in contact, the fluid will rise higher *between* the balls than at any other point.

175. If the balls be not wetted with the liquid, they will appear to partially sink in the liquid as in a cushion. If near enough, the repulsion exerted on the water will render the surface between them *concave*; thus the balls *will be pushed together*, and appear to attract. But if a ball of clean moistened cork and a ball of wax be floated near each other, the reverse takes place, the water being heaped up round the cork ball, and depressed round the wax ball; they appear to repel each other since the cork ball attracts the fluid repelled by the wax.

176. A body partly immersed in a liquid which wets it is apparently attracted by another body in a similar condition; little balls of cork are attracted to the edge of a basin of water in which they float; air-bubbles, arising from sugar being dissolved in tea, are first attracted to each other, then to the spoon, and as soon as the latter brings them *sufficiently near*, rush to the side of the cup.

177. The effect of the concavity or convexity of surface has been very prettily arranged for optical projection by Dr. Connor Sloane. He uses a *short* cylindrical glass tube, an

inch in diameter, the lower end being drawn out to the width of quill tubing. To the quill tube he attaches, by means of india-rubber tubing, a small filter funnel. The tube and funnel contain water. The cylinder is placed on a ring of wire, the handle of which is curled round an upright rod as a support. A Christmas-tree ball or silvered bead, the aperture having been closed with sealing-wax, is floated in the tube. So long as the tube is not quite filled with water, the ball stays against the side. Now *on raising the funnel* the liquid rises in the tube, and if the edges be coated with paraffine, bees'-wax, or lycopodium, the water may be made to rise *much higher* in the tube, forming a convex surface. The ball now sails away from the side, and remains on the top of the liquid mound. When the funnel is lowered, it returns to the side; when the funnel is raised, it instantly sails to the centre. With a paraffine bead the reverse takes place.

178. Tubes of slightly different bore may not be easy to get; the result is just as well shown by the thin prism (Home Experiment 99*a*), or by using two inclined plates of glass (about 4 inches square) partially immersed in water coloured with aniline dye. The liquid rising between them forms a beautiful curve known as the *rectangular hyperbola*. What we call capillary action, whether exerted in capillary (L. *capillus*, a hair) tubes, between plates of glass or floating bodies, is the *result of Surface-tension*.

179. In the case of plates or tubes standing in water, the elastic film of water is attached by one end to the plate or the tube, and exerts its contractile force in pulling up the water. We know exactly how much energy it has—16·62 grains per square inch. A tube of 1 inch bore will lift up 16·62 grains of water. A tube of twice the bore will lift up *twice as much* water above the water-level. The column will not, however, be raised *twice as high*, for that would mean raising *four times* the former weight. The column in the second tube will therefore be only half as high. In a hair-like tube the water, though proportionately the *same in quantity*, is raised to a *very* great height.

This is easily shown by dipping one end of piece of prepared chalk into coloured ink or aniline dye.

180. Another lantern projection, is that of a drop of water placed in the wide end of a tube drawn out to a point. The axis of the tube being horizontal, the drop becomes bounded by two concave surfaces; the one near the apex being *most curved*, the drop moves in that direction, attracted by the sides of the tube.

181. Closely allied to capillarity, are the phenomena of *endosmose* and *exosmose*, by which two fluids, separated by a porous partition, become mixed. In general, the fluid which has the greatest capillary attraction for the partition passes through and mixes with the other fluid. This *diffusion*, as it is termed in the case of gases, is admirably shown by the soap-bubble. The mouth of a porous cup, *e.g.* a very small and clean flower-pot with the central hole stopped, or, what is much better, a cylindrical porous cell, such as is used in the Bunsen battery, is inverted and its open end dipped in soap-solution. A glass jar of hydrogen or coal-gas is then inverted over it. The hydrogen diffusing through the pores into the interior of the cell blows out the film into a bubble. On removing the glass jar the action is reversed, and the bubble collapses.

182. It is in consequence of the tension or *contraction* of the film that small quantities of liquids are drawn into perfect spheres. Every rain-drop and every dew-drop is a perfect sphere, enclosed, as it were, by an elastic film which pulls it into the shape which has *least outside*. The surface exerts the same force whether the drops are large or small, but it is not the *only* force to which the liquid is subject. There is the pulling of the Earth which we speak of as *weight*, and this increases with the mass. There is also the *adhesion* or attraction which the side of the containing vessel, if any, exerts, and the *cohesion* of the liquid particles among themselves. When the quantity of liquid is large, it is too much pulled down to the earth—too much flattened. But the weight of a soap-bubble is practically *nil*; therefore we need regard only the surface-

tension. A bubble is a perfect sphere. It was to get rid of the attraction of the Earth on drops of liquid, that Plateau had recourse to oil and the alcohol mixture. Several illustrations are given in the text. Allude also to the making of shot. The molten lead is simply poured through perforated vessels from a high tower.

183. With suitable precautions we can also make the cylinder. Plateau spent much time in producing this figure and learning its laws. The method given in the text was his latest and least troublesome. He also produced the cylinder by manipulating a bubble between two identical rings, and in other ways ; but perhaps the most satisfactory is to blow a bubble on the end of a small funnel, and draw it out with a similar funnel, blowing air in or sucking it out, as required, to straighten the sides. He found that when the cylinder was half as long again as its diameter it became awkward to manage. It divided itself into two unequal portions, one having the sides convex, the other concave, and that when the length was just over 3 diameters ($3\frac{1}{7}$ diameters, thus corresponding with the circumference) it did not last for a moment, but broke up into a series of balls united by fine liquid threads, which soon severed, releasing the large and small spheres, which then descended in a column.

184. We may also show the formation of drops and cylinders, by employing a solution of sulphate of zinc, which has the same free surface-tension as water. We can give the zinc a density greater than, equal to, or less than carbon bi-sulphide, which we propose to drop into it. Sir W. Thomson, who showed this experiment at the Royal Institution, coloured the bi-sulphide with iodine. The formation and subsequent breaking-up of a liquid cylinder is shown to be the same process as may be observed in the slow dropping from the water-tap.

185. II. The likeness of the soap-bubble to an indiarubber ball in pressing on the enclosed air is sufficiently illustrated in the text. But there is one point which I have not insisted upon : that is, that the pressure is indicated by the curvature, since the film

is always stretched by the same force. Thus the curvature is greater in a small bubble than in a large one. The pressure has also been shown to be greater. If we cut up wire rings of different diameters we shall find, on selecting the *same lengths of wire* in each case, that those which formed parts of small rings are much more curved than those of large rings. If the ring be very large indeed, a little piece of it will seem almost straight. The correspondence of curvature and pressure is seen in a group of bubbles. Where two equal bubbles meet, the partition-wall is *plane*. But where a little bubble touches a larger, the partition is curved, and the small bubble presses into the side of the larger with great force. Never more than *three* bubbles meet in a point, since the *group* obeys the same law as the individual bubbles—that of *least surface*.

186. III. The surface of a liquid is more or less viscous than the interior. Treacle is a good illustration of a viscous substance. Dip a spoon in water. The particles of water slide over one another, and move out of the way on every side, but a spoon dipped in treacle meets with resistance; the particles do not move so easily; they are more dilatory, as it were, and accumulate in front of the spoon.

187. *Saponine*, prepared from the horse-chestnut, has a marked effect on the water-surface. Blow a bubble with saponine and water, and instead of allowing it to blow itself out, suck the air out. The skin cannot contract as quickly as the bubble expires, consequently it *wrinkles up* in a purse-like form, similar to the squeaking bladders sold in the streets. Another striking experiment is to suspend a magnet (1) immediately *over* the surface, (2) *on* the surface, and (3) immediately *beneath* the surface of water containing 2 per cent of saponine. The suspended magnet in cases (1) and (3) is eagerly attracted to a magnet held in the hand; in case (2) movement is almost impossible.

188. *Additional Notes.*—A clay pipe may be united to the ·et by indiarubber tubing, and in this way balloon bubbles

may be blown. It is not safe to make these in the evening when the gas-jets are lighted, or in a room where there is a fire. The only safe place is outside. I do not recommend these bubbles; my own plan with heated air is free from all risk, and allows the bubble to ascend gracefully, instead of *rushing* up to the ceiling and staying there.

189. Another proof of the *viscosity* of the water film is shown in floating needles. Turn up the ends of a hair-pin through an angle of 15°. Lay the needle in this cradle, and gently lower it, one end at a time. The needle is supported by the *viscous* surface; placed *anywhere beneath* that surface it instantly sinks.

190. One of the most interesting points in this inquiry is how a bubble bursts into a cloud of fine dust. We know that this takes place when the black spots indicate that the film is too thin to last. At first a hole is made, and, as we saw by the threads in the ring, the rent is made worse by the surface-tension. The descending liquid is heaped up round the margin of the hole, forming a ring. This ring, being unstable, goes through a series of transformations, ending in drops which are scattered on all sides. Another ring forms in the same way, and *instantly* breaks up. Other rings follow in rapid succession, the dissolution of the whole bubble into fine cloud occupying a minute fraction of a second.

191. *Laws relating to the Arrangement of Laminar Systems.*—"1. From each of the edges of the solid frame proceeds a film.

"2. If care be taken that there be no bubbles of air on the surface of the liquid in the vessel before immersing the frame, the laminar system will present no space closed on all sides by films; in other words, each of the films of the system will be in contact by its two faces with surrounding air.

"3. At the same liquid edge not more than three films ever terminate, and these make with one another equal angles.

"4. When several liquid edges terminate at the same point in the interior of the system, the edges are always four in number, and form between them equal angles.

"5. When the conditions can be fulfilled by plane surfaces the films take that form; when this is impossible, all the films, or several of them, are more or less curved, but always in such a manner as to constitute surfaces of mean curvature *nil*. The first takes place, for example, in the systems of the tetrahedron, of the triangular prism, and the octahedron; the second in those of the cube, hexagonal prism, etc."—*Plateau.*

192. *Frame.*—A form representing the cells of the honeycomb is produced by dipping two wire frames having hexagonal meshes. Place so that the point where three hexagons meet in the one frame is just over the middle of a hexagon in the other. Slightly separate the frames.

Chapters XXXI and XXXII

276. 193. The moon's mean distance from the earth is about 238,800 miles; she is sometimes as near as 221,600 miles, and at other times nearly 253,000 miles distant. Like Earth (Fig. 151) she moves in an elliptical orbit. Her period of revolution is 27 days, 7 hours, 43 minutes, and as she rotates on her axis in the same period, (1) she always presents the *same face* (hemisphere) to Earth; (2) this is also the length of her day. The moon's diameter is about 2160 miles. The earth is about 49¼ times as large (*volume*), and is 80½ times as heavy. Therefore, the moon is composed of materials little more than half (or 0·612) as heavy as the earth. The force of gravity on the moon is reduced to about one-sixth (or 0·1673) of terrestrial gravity. The area of the moon's surface is about equal to the continent of America, and the portion which we see is about equal in area to North America. Owing to a swinging motion (*libration*) of the moon, a portion of the other side near the eastern and western limbs, is also brought into view; so that we see at different times altogether some 59 % of the whole surface, while 41 % is manently invisible to the dwellers on earth.

94. In addition to the moon's rotation on her axis, she also

revolves round the earth, and the period from new moon to new moon is the axial rotation + the time required to bring her into the same relative position as before with reference to the sun and earth. This amounts to 29 days, 12 hours, and 44 minutes. Illustration :—The minute hand and the hour hand of a clock are both at 12. The minute hand now makes one revolution. But the hour hand has also moved on, yet not at the same rate ; while the minute hand has proceeded all round, the hour hand has gone but one-twelfth of the way—it stands at 1. By the time the minute hand has gained the next five minutes the hour hand has moved nearly half a minute further. This may be shown by a clock or watch.

280. 195. Many people who know that there are craters on the moon are inclined to doubt the existence of mountain ranges. The most important mountain ranges occur in the north, where craters are fewest, and "seas" abound. The Apennines extend for 450 miles, and contain upwards of 3000 peaks. Mount Huyghens, one of these, rises to 18,000 feet. The Caucasus, a diverted northern extension of the Apennines, contains many lofty peaks from 11,000 to 14,000 feet high, and one almost as high as Mount Huyghens. The Alps comprise some seventy peaks, and an immense valley 80 miles long and about 5 miles broad. So straight is this valley as almost to suggest the "cutting" of a lunar canal. Isolated peaks are also found upon the moon ; thus Pico rises abruptly from a smooth plain to a height of 7000 feet.

196. The lunar volcanic crater Aristarchus "has a circular rampart nearly 28 miles in diameter, the summit of which is about 7500 feet above the surface of the plateau, while its height above the general surface of the moon is 2600 feet." A central cone, having several subordinate peaks, completes the true volcanic character of this crater. Several very notable cracks or chasms, 2 or 3 miles wide in places, radiate to the north. Some of these parallel gaps seem to be partially filled by masses which have fallen inwards from their sides. Several smaller craters are scattered around. These, together with the gigantic

chasms and ridges, add to the wild weird grandeur of the scenery. The comparative isolation of Aristarchus tends to make the bright radiating streaks more conspicuous in this instance, although they are common to several of the larger lunar craters. The light-reflecting property of the rampart banks and ridges has led to much speculation. Mr. A. C. Ranyard, in an interesting article in *Knowledge* (May, 1890), gives his reasons for believing the light to be reflected from snow or hoar-frost.

197. Copernicus, one of the grandest and most instructive of lunar craters, is very conspicuous in Fig. 129. It is the more westerly of the two adjacent bright objects shown in the lower half of the disc. Although not the largest, it is one of the most impressive, and in many respects the most interesting of the Moon's features, and owing to the strong family likeness of lunar craters may be regarded as typical. These craters vary in diameter up to 78 miles, one of the tiny enclosed ones being but $1\frac{3}{8}$ miles. Copernicus measures 46 miles across. The vast rampart rises more than 12,000 feet above the centre of the plateau. From within rises a group of cones, three of them being over 2400 feet. For upwards of 70 miles round Copernicus there are myriads of comparatively minute but perfect craters, especially on the south-east side. Some of these appear to stand upon bright radiating streaks similar to those noticed in Aristarchus. A photograph of Copernicus shows the surrounding country pitted over with minute craters, reminding one most of air-bubbles (punctured) on a gelatine surface, such as a "graph" composition presents at times.

198. Due west from Copernicus in Fig. 129 is a circular mountain (*Erastothenes*), and proceeding west with a slight curve downwards (i.e. *south*) are the Apennines. Following the mountains, and partially enclosing three craters on our right, the largest of which is Archimedes, the chain diverts a little to the south, and is followed in the same direction by the Caucasus Mountains. Notice the radiant crater to the east of Copernicus. It is

Kepler. Now look south ; see how thickly the surface is set with craters. Those portions of the moon occupied neither by mountains nor craters are called "seas." Note that Fig. 129 represents the moon (inverted), as seen through a telescope. To identify it with the moon seen by the *eye alone*, it will be necessary to turn the book upside down.

199. For the practical details in presenting this chapter I cannot do the lanternist greater service than to recommend him to see a copy of the *Scientific American* for 9th April 1892, which, by a curious coincidence, has just been placed in my hands as I write. It will open out a new world to him, and stimulate him to greater efforts in the future.

200. A writer in the *Academy* recommends an imitation of the craters and inequalities of the lunar surface, produced by throwing pebbles into mortar. Mr. Meydenbauer of Marburg used a basis of dextrine for the purpose, and dropped small quantities of the same material from a moderate height. Photographs of this, present a great similarity to those of the lunar surface.

201. The revelations afforded to us, during solar eclipse, of the grandeur of our great sovereign are but as glimpses at the portal of the Royal Palace compared with the splendour of King Sol's true presence.

Mother Earth, in solicitude, presses us so closely to herself, and so draws the ample folds of her garments protectingly around us, that we are borne aloft through space, scarce knowing whither we go, or what we see. But suppose that we could look through some little *peep-hole* ? Then we should see him as the little folks might have seen him from the moon. A gorgeous spectacle ! King Sol seated upon his throne in the black heavens closely set with diamonds ! Naturally, we remarked upon the *intense white* glare of the central mass, no longer a disc in appearance, but, being slightly less brilliant at the circumference, it seemed as though Nature with a very soft pencil had toned down the radiance about the edge of the disc, just enough to

bring out in relief his spherical form. On this globe certain features were very distinctly visible; some looked like dark cavernous hollows (*maculæ*), ever changing in form; others were streaks of unparalleled brightness (*faculæ*). Wrapping round this intensely white heart of fire was a delicately coloured circular mantle, not ruddy, as seen in total eclipses viewed from earth, but bearing the faint blush of the rose, with its complementary hue of green, mingled, not mixed, the coloured light changing with our position or the flickering of the flaming mass. Out of this rose-pink and green-coloured band, ever and anon there sparkled forth rocket-like showers and flashes of orange or of gold. Higher still, leapt up tongues of flame of varying height, new colours intermingling with those before mentioned, notably dark purple and blue rays darting out from between orange and gold, dancing up and across even the loftiest of the jutting flames with a strange flickering effect. In the bright equatorial region these leaping flames assumed rather the shape of hurrying clouds constantly varying in form. Surrounding this flaming envelope, a luminous atmosphere shone with iridescent lustre, reminding us of mother-of-pearl or the mixed lights of the soap-bubble. This atmosphere extended beyond twice the height of the flaming tongues, while outside of this was a bright but fainter halo of whitish light, whose beams branched and extended far away and were lost in the abyss of space. Even out of this atmosphere and its fainter halo, there rose luminous ribbons. Streaks of opal light and jets of silver light burst forth, sometimes crossing each other, forming a kind of glittering veil; while from among these, finest silken threads of silvery light, too brilliant to behold, streamed into the observer's eye.

Chapter XXXIII

294-303. 202. Sugar ground in the mortar, in a dark room, is very effective; fluor-spar, feld-spar, or chlorate of potash ay be treated in the same way.

203. Canton's phosphorus is made by heating clean oyster shells in a crucible, in the centre of the fire. The cleaner and finer portions are then reduced to powder. The crucible is filled with alternate layers of this powder and flowers of sulphur, and returned covered to be re-heated to dull redness for half an hour. It is then slowly cooled and transferred to a stoppered bottle.

204. Marbles, which emit a green light on slight heating or insolation (*exposure to sunshine*) can be made of—Barium Sulphate thirty-two parts, Magnesium Carbonate one part, Sulphur one part, and sufficient Gum Tragacanth to make them up. When dry, they are heated in a crucible at red heat for half an hour, and are placed in a stoppered bottle before they are quite cold. For red light, make marbles of Strontium Sulphate twenty-two parts, Sulphur one part, adding the gum as before.

205. Balmain's Luminous Paint is one of the best phosphorescent substances. Small articles, such as luminous match-boxes, crosses, etc., can be bought for a few pence, or the paint itself may be purchased.

206. It has been proposed to coat the walls of buildings with this paint, and to do away with street lamps.

207. Phosphorescence is quenched by red light—a significant fact.

Chapters XXXIV and XXXV

208. Experiments in Diffraction or the *Inflection* of Light succeed best with sunshine ; no other light is sufficiently strong to show all the phenomena very distinctly on the *screen*, but if *viewed directly*, as in some of the experiments given in the text, the light even of candle is effective. Next to sunshine comes the arc-light ; but most of these experiments can be shown with the lime-light under special conditions. The lanternist would do well to assume that *all* the experiments can be made with his lantern, provided the light be sufficiently strong.

209. The light must be concentrated to an *intensely brilliant*

point. (*a*) The small image of the sun formed in the focus of a powerful bi-convex or spherical lens is such a point. (*b*) The plan recommended for shadowgraphy is also suitable. (*c*) The image of a source of light, if large, is further reduced by passing through a lens (or lenses) of still shorter focus; but each lens robs the beam of a considerable amount of light. (*d*) Or, the light, after passing through a small circular aperture, may be allowed to fall on to the surface of a small silvered bead. I have found the bulb of a small thermometer useful. This *reflected* image is exceedingly brilliant.

210. Similarly, an *intense line of light* is obtained (*e*) By allowing the slice of light issuing from a vertical slit ($\frac{1}{8}$ to $\frac{1}{12}$ inch) to pass through a *cylindrical* lens, *e.g.* a test-tube containing water, held parallel with the slit. The focus of such a lens is a physical line. Or (*f*), the line may be obtained by *reflection* on substituting for the water, ink or mercury.

211. Gratings, single or crossed, perforated zinc or card, wire gauze, feathers, cambric, pearl, lycopodium halos, etc., give fine effects with the Optical lantern.

212. Light reflected from pearl, feathers, etc., is projected on the screen by the same arrangement as the soap-film (Fig. 102). Or, the feather is mounted on glass as a slide, and the light *transmitted* through it, as a grating. In this case, a broad pheasant's body-feather is selected. The rest of the slide is blackened, to ensure that the light passes only through the *slits.*

213. The perforated zinc is fitted in a wooden frame, and inserted in the slide-stage, and the image projected in the ordinary way on the screen; on holding a hand-screen nearer to the nozzle, the colour effects are very striking, and now, by drawing the objective further back, are made visible on the large screen. The screen distance most suitable for each case is found by trial, and noted *prior* to the lecture; with lime-light it may be about 10 or 12 feet, with a weaker light, about 4 or 5 feet away. When two sets of apertures are used, *e.g.* two perforated rds, they are separated by an interval of at least an eighth of

an inch, and the finer one is placed in front. Two geometric forms of parallel gratings (photographs) are included in the lantern slides.

CHAPTER XXXVI

214. The methods described in the text will be found to be more effectual than with the optical lantern, unless the arc-light or magnesium ribbon is employed therein.

323. 215. A decoction of horse-chestnut bark is powerfully fluorescent, but is liable to become brown from the tannin, etc., contained in it. By adding a little sesqui-oxide of iron (Fe_2O_3), precipitating by ammonia and filtering, the clear liquid shows fluorescence to perfection. The bark of the horse-chestnut contains two fluorescent bodies—*æsculine*, which fluoresces a bright blue, and *fraxine*, which shows a bluish-green fluorescence. The fraxine in a solution of the bark masks the deep blue of the æsculine, and this explains why bark solution reflects a *pale* blue light.

216. M. Zenger, observing a bluish fluorescent light from Mont Blanc after sunset, is said to have projected the image of the mountain, when thus seen on a plate of Balmain's luminous paint. He afterwards placed this in contact with a dry photographic plate for an hour, and obtained a permanent photograph of the mountain.

217. The following substances also exhibit fluorescence—

Sea-weeds. Professor Stokes found that certain varieties of red and reddish pink sea-weeds mashed in cold water, also their cold infusions, were most effective.

Nettles, boiled to remove the tannin, etc., and then steeped in alcohol. I preferred the tea-leaves as more readily accessible to children.

218. Other fluorescent substances are: turmeric or camwood steeped in castor oil; fustic steeped in alum; saffron or madder dissolved in alcohol. The aniline dyes—eosine, uranine, magdala

red, or naphthaline red. Cyanosine in alcohol; anthracene; thallene ground up with a rather thin varnish of gum damar in benzole; fifteen parts glacial acetic acid, and one part essential oil of peppermint, heated to nearly boiling point; uranium glass pounded finely and mixed with a transparent varnish.

327. 219. The crystalline lens is fluorescent. The cornea, and also the rods and cones of the retina, are also said to be fluorescent, but of these I cannot speak with certainty. A few days ago I visited an invalid, and placing my hand upon her temple to relieve the pain, I cut off the direct illumination from the gas—it was but turned up ¼ inch—and thus quite unintentionally favoured the observation of a remarkable phenomenon. I am not prepared to say that it was wholly due to fluorescence. The interior of the eye was only faintly luminous, but the cornea sparkled with *golden* light similar to that which I had previously observed in the bottle of dry quinine. It was not like the *sheen* of fluorescence; it was more like a fine golden thread gliding along in detached portions, and glittering brilliantly. I am inclined to the opinion that the effect must be referred to one of the fluids of the eye.

Chapter XXXVII

331-338. 220. It was my intention to insert a few notes on the principles of a photographic lens. Since then, my notice has been drawn to a pamphlet, issued by Messrs. R. and J. Beck of Cornhill, which deals with the subject in a manner at once so simple and thorough, that I have asked Mr. Chadwick to supply it on receipt of postage.

221. The five points to be noted in a photographic lens are—(1) Focus; (2) Depth of Definition; (3) Angle of View; (4) Rapidity; (5) Distortion. Let us see how the pin-hole compares with the lens in these matters.

(1) Focus has been explained in the text.

222. (2) Definition is the power of a lens to give *sharp*

images in one plane of objects at different distances. A pin-hole is the only lens which does this *absolutely*. *A pin-hole has unlimited depth of definition.*

223. In photography, this quality is approximated by selecting a lens of short focus (the shorter the focus, the greater the depth) and *stopping* it down, by using a diaphragm with a *small* aperture. The iris of the eye is just such a stop. A lens with the aperture thus very much reduced approaches the pin-hole, and the resulting pictures are practically the same. On referring to Fig. 45, it will be seen that the rays which pass through the *centre* of the lens are not refracted (Notes 43, 44), hence the increased depth of definition.

224. (3) Angle of View is the amount of field covered by the lens. With a pin-hole, photographs of any size can be taken: practically the *whole scene* in front of the camera will appear on a photographic plate placed near to the hole. This view would include some 130° or more, which is almost as much as can be seen by the human eye at rest. This *angle* of view (130°) is *very large*. In order to use the plate so *near to a lens*, we should have to select a lens of very short focus or *wide angle*.

225. (4) The Rapidity of a lens depends on—(*a*) the aperture, (*b*) the shape and number of the glass surfaces through which the light must pass, and (*c*) the colour and transparency of the glass. Although the pin-hole is not subject to hindrances (*b*) and (*c*), yet *so very few rays* get through a pin-hole, that the plate requires to be exposed for a long time. The further the plate is removed from the aperture, the longer must be the exposure.

226. (5) Distortion. A pin-hole has *no distortion*; the straight, horizontal, and vertical lines in Nature are faithfully reproduced on the plate. The further we move the plate back (keeping the pin-hole of the same diameter), the larger will be the image of *each object* in the photograph, and the less of the subject will be included on the plate.

227. For ordinary purposes, Professor Pickering uses a screen-distance not greater than 12 inches. With a shorter focus, he

says that the aperture should not exceed $\frac{1}{50}$ inch, nor be much less than $\frac{1}{100}$ inch. If smaller than this, *Diffraction* comes into play.

228. A camera in accordance with these principles is supplied with the apparatus. It will take photographs similar to that reproduced in Fig. 140. The price, 2s. 6d., includes rapid plates, developer, etc., instructions, and exposure tables. This is not a cardboard toy, but a carefully made, substantial, light-tight instrument, covered in morocco cloth. The aperture, $\frac{1}{50}$ inch, is drilled in iron-plate, and a receiver or slide-stage, for a photographic plate ($4\frac{1}{4} \times 3\frac{1}{4}$), is placed at a distance of $6\frac{6}{7}$ inches behind the pin-hole. The exposure at noon varies from 45 seconds during the summer months to 3 minutes in December.

229. Lord Rayleigh, in a discourse before the Royal Institution (and reported in *Nature* of 16th July 1891), showed that photographs could be taken with holes much larger than pin-holes, provided that the plate be removed to a distance of some feet. He argues—"The truth is that we are in the habit of regarding this subject in a distorted manner. The difficulty is, not to explain why optical images are imperfect, no matter how good the lens employed, but rather how it is that they manage to be as good as they are. In reality the optical image of even a mathematical point has a considerable extension; light coming from one point cannot be concentrated into another point by any arrangement. There must be diffusion, and the reason is not hard to see in a general way. Consider what happens at the mathematical focus, where, if anywhere, the light should all be concentrated. At that point all the rays coming from the original radiant point arrive in the same phase. The different paths of the rays are all rendered optically equal, the greater actual distance that some of them have to travel being compensated for in the case of those which come through the centre by an optical retardation due to the substitution of glass for; so that all the rays arrive at the same time. If we

take a point not quite at the mathematical focus but near it, it is obvious that there must be a good deal of light there also. The only reason for any diminution at the second point lies in the discrepancies of phase which now occur; and these can only enter by degrees. Once grant that the image of a mathematical point is a diffused patch of light, and it follows that there must be a limit to definition. The images of the components of a close double point will overlap; and if the distance between the centres do not exceed the diameter of the representative patches of light, there can be no distinct resolution. Now their diameter varies inversely as the aperture; and thus the resolving power is directly as the aperture. However perfect your lens may be, you cannot get good definition if the aperture is too much restricted. On the other hand, if the aperture is much restricted, then the lens is of no use, and you will get as good an image without it as with it."

230. The relation between the screen-distance and the aperture may be determined by the formula $r = \sqrt{(f\lambda)}$, where r = the radius, and f = the focal length or the distance between the aperture and the screen. Lord Rayleigh proved by experiments and by photographs that a simple aperture is as effective as the best possible lens, provided that the focal length is sufficiently great.

231. Pin-hole photographs being absolutely correct, require no *re-touching*. They may also be enlarged to any extent—enlargement merely serving to bring out their beauty. Those interested in the subject should see the beautiful photographs of the sky, produced by this method, which have appeared from time to time in *Knowledge*.

232. Fig. 141 should not create a wrong impression: no focussing or finding is required. The Artist's endeavour has been to show the *principle* of the pin-hole photograph. In *practice*, it is merely necessary to place the camera on a table or high stool, etc., and point it to the object to be photographed. Or when employing rapid plates, it may be held

under the chin (Note 5) as a hand-camera. A view, almost *identical* with that which the observer sees, will be impressed upon the plate, after withdrawing the cap from the "pin-hole lens."

233. For the sake of the Children, I will simplify the formula given in Note 230, by working out an example step by step. To find where to place the screen—

(1) Divide the diameter of the hole by 2.

(2) Multiply this number by itself.

(3) Divide the result by $\frac{7}{480,000}$.

(4) The answer now obtained gives the number of inches.

234. Let us suppose that we have made a hole $\frac{1}{50}$ inch in diameter, and wish to know how far away to place the screen or photographic plate.

(1) The diameter $\left(\frac{1}{50}\right)$ is to be divided by two; $\frac{1}{50} \div 2 = \frac{1}{100}$.

(2) This number $\left(\frac{1}{100}\right)$ is to be multiplied by itself;

$$\frac{1}{100} \times \frac{1}{100} = \frac{1}{10,000}.$$

(3) The result $\left(\frac{1}{10,000}\right)$ is to be divided by $\frac{7}{480,000}$;

$$\frac{1}{10,000} \div \frac{7}{480,000} = \frac{1}{10,000} \times \frac{480,000}{7} = \frac{48}{7} = 6\tfrac{6}{7}. \quad \textit{Ans.}$$

The *best* definition will be obtained at $6\frac{6}{7}$ inches from the pin-hole (see Note 228).

235. Again, suppose that we desire to take a large photograph in any ordinary room, having first closed the shutters and refused admittance to stray light. Let us look again at Fig. 11. How far is the screen from the shutter? We will suppose, for example, that it is *seven feet*. We now ask ourselves, "What size shall we make the hole in the shutter?" As we want our answer in *inches*, we shall first reduce our 7 feet to 84 inches.

(1) Multiply (84 inches) the screen-distance by $\frac{7}{480,000}$

$$= \frac{84 \times 7}{480,000} = \frac{49}{40,000}.$$

(2) Take the square root of this fraction (numerator and denominator separately).

Now $\frac{49}{40,000} = \frac{7 \times 7}{200 \times 200}$; therefore the square root is $\frac{7}{200}$.

(3) Multiply this square root by two; $\frac{7}{200} \times 2 = \frac{7}{100}$. *Ans.*

The most suitable diameter to give the hole is $\frac{7}{100}$ inch.

236. But, you may ask, "How shall I make a *small* hole of a certain size?" Shall I tell you how Newton made the pin-hole referred to on page 310? He took a number of pins, exactly alike, and placed them side by side—arranging, I suppose, heads and points alternately—and found that forty-two pins took up the space of one inch. Therefore one pin was $\frac{1}{42}$ inch in diameter, and the hole, struck perpendicularly—*not sideways*—was of the same diameter as the pin that made it. "But $\frac{7}{100}$ inch puzzles me," you say. Let us read it another way: $\frac{7}{100}$ inch also means the one-hundredth part of seven inches. One hundred pins of the required thickness will take up exactly *seven inches.*

A group of cedars, taken under these conditions by Lord Rayleigh in an ordinary room, carefully darkened, showed "nearly as much detail as could be seen direct from the place in question." (The photograph was taken on a 12×10 inch plate placed at a distance of 7 feet from the hole ($\frac{7}{100}$ inch) in the shutter.)

237. Notwithstanding that I have advocated at some length Nature's Simple Photographs, let it not be supposed that I depreciate the Photographer's Art. It is the function of *Sunshine* to reveal the broad principles which underlie phenomena. I leave the rest, in full confidence, that no one, who has worked through this book, will ever be satisfied with empirical knowledge, or be persuaded to convert himself into an Automaton by the device—"You press the button—*we will do the rest.*"

NUTS

SOME of these are very hard, but all will yield to the nut-crackers of *Experiment*. Take only one at a time. They are *real* experiments made by various persons without the slightest intention, indeed almost unconsciously.

1. On passing out of our Town Hall, one evening, I observed a curious representation of myself upon the wall close to me. I wondered where I had seen something like it before, and presently called to mind a number of tall glass shades placed within each other in the window of the glass shop. What arrangement gave rise to the wall figure?—A. J.

2. A schoolmaster was called away from teaching to speak to a gentleman who was waiting in another room. Having placed his class in the hands of an assistant, he was proceeding to his room when he (apparently) observed the class and its teacher revolve through a semicircle (S.E. to N.W.) On his return he saw them wheel round again and take up their former positions. On inquiry he learned, to his surprise, that neither the teacher nor any pupil had moved from his place. How do you account for the master's illusion?—J. M.

3. The other night I was somewhat amused to see the ·verted image of a flame capering about on the shutters of hop across the way. The owners had shut up and gone

home, so I don't fancy they knew what was going on. Do you?—A. J.

4. "Mother!" said a little girl on going up to bed, "Mother, this room is full of something; guess what it is?"

"Full of air?" asked the mother, well used to her daughter's puzzling questions.

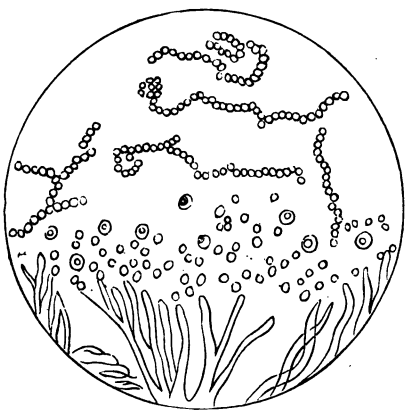

FIG. 168.—"WHAT GWNYETH SAW."

"No, I don't mean that—guess again," said little Gwnyeth.

"Full of darkness?" suggested the mother.

"No," said she, gazing down on the candle-beams, as she spoke—"Shall I tell you? It's full of snakes and things."—Mrs. S.

5. The window of my study looks out to the west. It was at the close of one of the brightest and clearest afternoons of last summer that a visitor called upon me; and I, rightly judging the flood of light to be inconveniencing my friend, drew down the Venetian blind and darkened it. After we had talked a little while I rose to get something,

and in doing so passed quite near to the window. I fancy that one of the blind staves, on a level with my eye, was not quite so close as were the others; for it seemed as though the sun itself, just on the point of setting, were being shot into my eye. Stunned by the sudden light, I involuntarily frowned, and then there seemed to proceed direct from the sun into my eye innumerable fine silken threads of every colour, not woven together, but each as it were a telegraph wire from the heavens to earth. It was a glorious sight! I was very, very glad, but not so much surprised at this, when I came to think of it; but what really did surprise me (and I have not wholly fathomed the mystery yet) was that at apparently not more than an inch from my eye, was a large circular patch of a bluish-green and violet colour. It remained but for an instant, and no amount of coaxing would bring it back. I do not know how to direct you to make this experiment, for, as you would probably say, the thing "did itself." I took no conscious part in it.—A. J.

6. I remember a short time ago picking up some lovely iridescent shells on the coast near Bangor, County Down. I put them away in a drawer, and when I came to look at them again I could not believe they were the same. The rainbow tints were gone, and apparently only a few common little periwinkles were left. To what was the iridescence due? Not to sea-foam, for the shells were quite dry when put away.—A. J.

7. "I know how many gases you've lit, and I haven't looked," said Jessie; and she was right too. How do you think she knew?—J.

8. One evening Harold was telling his father at tea, how, looking up at the windows of the empty house at the [illegible]r, he had seen people walking about inside. After tea

Harold's father went round with him and saw what Harold had seen; more than that, he saw himself (apparently) in the dining-room. I need scarcely tell you that Harold and his father settled the matter satisfactorily before coming home.—J.

9. (*a*) If, after looking at a well-lit window for an instant, I close my eyes, I see an image of the window with its white bars and darker panes, and now, as I turn my eyes to some brilliantly illuminated surface I see a *negative* image of the same, *i.e.* white panes and black bars.

(*b*) On gazing again at the window I see its white sash and darker panes; but after continuing to look steadily for two or three minutes, on closing the eyes or on turning them to some dark part of the room, I see the negative image as before.—R. C. P.

Note.—This experiment succeeds best first thing in the morning after the eyes have had a night's rest.

10. A few days ago, as I was about to wash my hands, I perceived a number of small discs of light focussed on the interior of the basin itself. It was a pretty sight. The water had rushed boisterously out of the tap, mixed with a considerable quantity of air, consequently there were numerous bubbles floating in the liquid as well as on its surface. Each of these air-bubbles acting as a lens focussed the light of the gas-jet, which was fixed vertically above the basin. (You see I have cracked this nut for you, lest you should go without.) —A. J.

11. This morning the sun shone brightly in forming a shadow-image of the window upon the floor, and as I looked at it I observed the bars lift up and occupy a higher position for a minute, and then quietly return to their old places. It was a very strange appearance, and would have

made some folks tremble to see it. Can you tell the reason of the shifting?—J.

12. When I was staying the other day at Orchard Lea, in Windsor Forest, I did most of my writing in a spacious window on the first floor, looking out over the garden. When the sun was high in the sky, and the French window was set open at a certain angle, the whole of the flowers, figures, etc., on my right appeared upon the lawn on the left hand as vividly as if they actually existed in duplicate. *So real was the illusion* that for some hours I was under the impression that a broad yellow gravel path actually stretched across the lawn on my left. It was only when a little dog ran along the spectral path and suddenly vanished into thin air that I discovered the illusion. Nothing could be more complete, more life-like. The real persons who walked up the gravel to the house walked across the spectral gravel apparently in duplicate. Both could be seen at one and the same time. I instantly thought that they could be photographed, so as to show the duplication produced by the illusion. Unfortunately no such impression was left upon the photographic plate. Why?—W. T. S.

13. In the tram-car the other day, in the twilight, I observed a curious effect, of which perhaps you might draw a diagram when you become more skilful. I was seated about half-way up the car on the left-hand side, and it appeared to me, as I looked through the top window, that the conductor (whom I knew to be on my right, gazing out upon the scene we were leaving) was riding as a postillion on the front horse. The solution is very simple, and yet the illusion was so perfect that, had I not known the optical principle of the case, I believe I should have maintained the *reality* of what I saw against all argument to the contrary.—A. J.

14. A gentleman sat by his fireside reading the newspaper. Presently the fairy sunbeams caught a glimpse of him sitting alone, and performed, as is their wont at times, an experiment which set him thinking. By means of a lustre on the mantelpiece, they threw down a spectrum on the paper he was reading. What did he care? He simply took no notice until he came to read the lines where it was, when he discovered that the print under *some of the colours appeared blurred.* Then his curiosity would not let him rest till, having asked many people and thought much about it, he at last ascertained the cause. Can you not guess?—S.

15. In going to a certain station I used to walk along a high street. A little to my left was a footpath, railed off on either side, and leading to the same place. I could not help being attracted by the animated appearance of these railings. They always seemed to be in a great hurry, even though I were walking slowly. This was but one of their peculiarities; another, which I cannot fully describe, was that in some positions the rails appeared to be magnified, and in other positions the gaps appeared to be magnified. The only way to get an idea of these phenomena is to try the experiment.—A. J.

16. I have a sewing-machine of polished walnut, incorporated with which is a writing-desk, occupying the back portion. When the machine is in use the walnut slab forming the lid is raised and thrown *slightly backwards,* reclining upon the desk. The machine was drawn across a corner of the room, so as to form the base of a triangle, enclosing the fireside on my right and the window on my left as I sat at work. I had been sewing a long piece of material, and, it being dinner-time, I looked down to see how much more I had to do, when in the triangular space, and near to the

window, my eye caught sight of a full-sized figure of myself (from the waist upwards). The image was lower than myself, but clear enough, with brown hair and eyes. At its neck was a bright red bow, coming unpinned. Its white linen collar was turned up at the right hand corner. At dinner I told my brother George, saying that I had seen Pepper's Ghost, and stating that I had been able to *look through it* at the wall and the side of the machine. He reached a mirror and held it before me. Then I saw that my bow was coming unpinned, and that the right point of my collar was turned up. Our correspondent adds that she thinks it could not have been a reflection or the *left* point of the collar would have been turned up. On this point refer to p. 403, also to Fig. 42. First determine what were the two mirrors unconsciously employed, then make a drawing on tracing-paper, marking the positions of the mirrors as stated above, and trace the primary and secondary images.—*Per* W. T. S.

17. I had been looking intently at a candle-flame some time, when my attention was called to something going on at the other end of the room, and I was astonished to find that the candle-flame followed my eyes there also; and as the image gradually faded, I observed that it passed through various stages of colour—orange, red, violet, indigo, blue, and bluish green.

Being interested, I again gazed at the candle and tried the effect of the ceiling as a screen. The after-image appeared at first almost black, which changed to deep blue, and passed through green to yellow, from yellow it finally merged into the whiteness of the screen itself.—G.

18. One night, observing that my watch, hanging up on a mantelpiece, and the flame of a candle not far away were nearly on the same level, the thought occurred to me

that by walking backwards I should find a certain position in which, while the right eye should only see the flame, the left eye would see nothing but the watch. I was curious to note the result. Having found the position, I succeeded (apparently) in getting the candle-flame to burn on the ring of my watch.—A. J.

19. Close one eye, and, holding the finger up in front of the other, look at one of the white bars separating the window-panes. When only a fine thread of light is seen between your finger and the upright bar the line of light becomes a spectrum. Moving the finger along to the *other side* of the same bar, the colours of the spectrum are seen in reverse order.—P.

20. "Ernest, run upstairs and fetch me a small parcel, which you will find on the table in my room—here, take this lighted taper, and carry it steadily!"

"Yes, mother," said Ernest, and he raced off as though he were being chased. "One, two, three, four, five, six," said he, counting the stairs as he mounted them, at the same time unconsciously marking time with the taper. "Seven, eight, nine, ten, eleven, twelve, thirteen;"—now he turns down a long corridor leading to the room directed, still in his high spirits wafting the taper to and fro, quite forgetful of his promise.

"Ernest!" called his mother. "Ernest! I'm waiting, dear!"

But Ernest heard nothing at all. Then she stole softly upstairs and found her boy gazing on the wall at the end of the corridor looking (apparently) at nothing.

"Oh! mother, did you see it?"

"See what, my son?"

"That great river branching out everywhere over the yellow sands."

under the chin (Note 5) as a hand-camera. A view, almost *identical* with that which the observer sees, will be impressed upon the plate, after withdrawing the cap from the "pin-hole lens."

233. For the sake of the Children, I will simplify the formula given in Note 230, by working out an example step by step. To find where to place the screen—

(1) Divide the diameter of the hole by 2.

(2) Multiply this number by itself.

(3) Divide the result by $\frac{7}{480,000}$.

(4) The answer now obtained gives the number of inches.

234. Let us suppose that we have made a hole $\frac{1}{50}$ inch in diameter, and wish to know how far away to place the screen or photographic plate.

(1) The diameter $\left(\frac{1}{50}\right)$ is to be divided by two; $\frac{1}{50} \div 2 = \frac{1}{100}$.

(2) This number $\left(\frac{1}{100}\right)$ is to be multiplied by itself;

$$\frac{1}{100} \times \frac{1}{100} = \frac{1}{10,000}.$$

(3) The result $\left(\frac{1}{10,000}\right)$ is to be divided by $\frac{7}{480,000}$;

$$\frac{1}{10,000} \div \frac{7}{480,000} = \frac{1}{10,000} \times \frac{480,000}{7} = \frac{48}{7} = 6\tfrac{6}{7}. \quad \textit{Ans.}$$

The *best* definition will be obtained at $6\frac{6}{7}$ inches from the pin-hole (see Note 228).

235. Again, suppose that we desire to take a large photograph in any ordinary room, having first closed the shutters and refused admittance to stray light. Let us look again at Fig. 11. How far is the screen from the shutter? We will suppose, for example, that it is *seven feet*. We now ask ourselves, "What size shall we make the hole in the shutter?" As we want our answer in *inches*, we shall first reduce our 7 feet to 84 inches.

(1) Multiply (84 inches) the screen-distance by $\frac{7}{480,000}$

$$= \frac{84 \times 7}{480,000} = \frac{49}{40,000}.$$

(2) Take the square root of this fraction (numerator and denominator separately).

Now $\frac{49}{40,000} = \frac{7 \times 7}{200 \times 200}$; therefore the square root is $\frac{7}{200}$.

(3) Multiply this square root by two; $\frac{7}{200} \times 2 = \frac{7}{100}$. *Ans.*

The most suitable diameter to give the hole is $\frac{7}{100}$ inch.

236. But, you may ask, "How shall I make a *small* hole of a certain size?" Shall I tell you how Newton made the pin-hole referred to on page 310? He took a number of pins, exactly alike, and placed them side by side—arranging, I suppose, heads and points alternately—and found that forty-two pins took up the space of one inch. Therefore one pin was $\frac{1}{42}$ inch in diameter, and the hole, struck perpendicularly—*not sideways*—was of the same diameter as the pin that made it. "But $\frac{7}{100}$ inch puzzles me," you say. Let us read it another way: $\frac{7}{100}$ inch also means the one-hundredth part of seven inches. One hundred pins of the required thickness will take up exactly *seven inches.*

A group of cedars, taken under these conditions by Lord Rayleigh in an ordinary room, carefully darkened, showed "nearly as much detail as could be seen direct from the place in question." (The photograph was taken on a 12×10 inch plate placed at a distance of 7 feet from the hole ($\frac{7}{100}$ inch) in the shutter.)

237. Notwithstanding that I have advocated at some length Nature's Simple Photographs, let it not be supposed that I depreciate the Photographer's Art. It is the function of *Sunshine* to reveal the broad principles which underlie phenomena. I leave the rest, in full confidence, that no one, who has worked through this book, will ever be satisfied with empirical knowledge, or be persuaded to convert himself into an Automaton by the device—"You press the button—*we will do the rest.*"

of the lake, bowed, and retired. What do you make of that?—A. J.

25. One of the most strange and weird sights I ever witnessed presented itself to me last week. The night was dark, and most of the business houses were closed—feverish haste had given place to an oppressive stillness. I looked up and observed poised in air, at a height of some 12 feet from the ground, a long table, stretching across from side to side of one of the principal streets of this city. Around this table were set about sixteen chairs, without visible support of any kind. Most of them were vacant, apparently waiting for their spirit-guests; but four or five were occupied by figures of grave aspect, intently writing. I asked myself what they could be so busily engaged upon, up to so late an hour. I gazed long and steadily and then called my young friend C., who seemed equally fascinated by the singular sight. *Real ghosts* they were, for through their transparent bodies we were able to read the signs over the shops. The table also was of the same unsubstantial materials; its top was still more shadowy—the paper appeared to rest upon nothing at all; while through the body of the table and the legs dangling in air, we clearly saw the objects exposed for sale in the railed shop windows. By and by one of the spectres rose to go. He had finished his story. He bore it away with him, gliding through mid-air into the darkness of night. Ah! who shall read that Ghost's story? What can it be about?—A. J.

THE END

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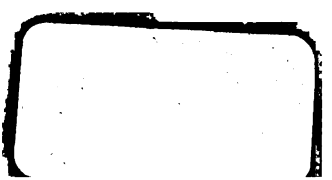

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